



National Aeronautics and  
Space Administration

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# AERONAUTICAL ENGINEERING

## A CONTINUING BIBLIOGRAPHY WITH INDEXES

(Supplement 253)

A selection of annotated references to unclassified reports and journal articles that were introduced into the NASA scientific and technical information system and announced in May 1990 in

- *Scientific and Technical Aerospace Reports (STAR)*
- *International Aerospace Abstracts (IAA).*



National Aeronautics and Space Administration  
Office of Management  
Scientific and Technical Information Division  
Washington, DC

1990

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# INTRODUCTION

This issue of *Aeronautical Engineering -- A Continuing Bibliography* (NASA SP-7037) lists 637 reports, journal articles and other documents originally announced in May 1990 in *Scientific and Technical Aerospace Reports (STAR)* or in *International Aerospace Abstracts (IAA)*.

The coverage includes documents on the engineering and theoretical aspects of design, construction, evaluation, testing, operation, and performance of aircraft (including aircraft engines) and associated components, equipment, and systems. It also includes research and development in aerodynamics, aeronautics, and ground support equipment for aeronautical vehicles.

Each entry in the bibliography consists of a standard bibliographic citation accompanied in most cases by an abstract. The listing of the entries is arranged by the first nine *STAR* specific categories and the remaining *STAR* major categories. This arrangement offers the user the most advantageous breakdown for individual objectives. The citations include the original accession numbers from the respective announcement journals. The *IAA* items will precede the *STAR* items within each category.

Seven indexes -- subject, personal author, corporate source, foreign technology, contract number, report number, and accession number -- are included.

An annual cumulative index will be published.

Information on the availability of cited publications including addresses of organizations and NTIS price schedules is located at the back of this bibliography.



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# TYPICAL REPORT CITATION AND ABSTRACT

NASA SPONSORED  
ON MICROFICHE

ACCESSION NUMBER → N90-10834\*# Old Dominion Univ., Norfolk, VA. Dept. of Mechanical Engineering and Mechanics. ← CORPORATE SOURCE

TITLE → AN EXPERIMENTAL INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF SLANTED BASE OGIVE CYLINDERS USING MAGNETIC SUSPENSION TECHNOLOGY

AUTHORS → CHARLES W. ALCORN and COLIN BRITCHER Nov. 1988 ← PUBLICATION DATE

CONTRACT NUMBER → (Contract NAG1-716)

REPORT NUMBERS → (NASA-CR-181708; NAS 1.26:181708) Avail: NTIS HC A05/MF A01 ← AVAILABILITY SOURCE

COSATI CODE → C\_SCL 01/1 ← PRICE CODE

An experimental investigation is reported on slanted base ogive cylinders at zero incidence. The Mach number range is 0.05 to 0.3. All flow disturbances associated with wind tunnel supports are eliminated in this investigation by magnetically suspending the wind tunnel models. The sudden and drastic changes in the lift, pitching moment, and drag for a slight change in base slant angle are reported. Flow visualization with liquid crystals and oil is used to observe base flow patterns, which are responsible for the sudden changes in aerodynamic characteristics. Hysteretic effects in base flow pattern changes are present in this investigation and are reported. The effect of a wire support attachment on the 0 deg slanted base model is studied. Computational drag and transition location results using VSAERO and SANDRAG are presented and compared with experimental results. Base pressure measurements over the slanted bases are made with an onboard pressure transducer using remote data telemetry.

Author

# TYPICAL JOURNAL ARTICLE CITATION AND ABSTRACT

NASA SPONSORED  
ON MICROFICHE

ACCESSION NUMBER → A90-13017\*# Texas A&M Univ., College Station. ← CORPORATE SOURCE

TITLE → IN-FLIGHT BOUNDARY-LAYER TRANSITION MEASUREMENTS ON A SWEEP WING

AUTHORS → ANWAR AHMED (Texas A & M University, College Station), WILLIAM H. WENTZ (Wichita State University, KS), and R. NYENHUIS (Cessna Aircraft Co., Wichita, KS) ← AUTHORS' AFFILIATION

CONTRACT NUMBER → (Contract NAG1-104) Copyright

JOURNAL TITLE

Flight tests were conducted at three different altitudes to detect transition on a smoothed test region of a swept-wing business jet wing using surface hot-film sensors and sublimating chemicals. Strong influence of sweep angle on transition location was observed when the aircraft was flown at some sideslip conditions to simulate changes in effective wing sweep angle. No effects of engine noise on transition were measured when different engine power settings were used. Flight instrumentation and ground data analysis techniques are described. Correlation was obtained between the hot-film sensor signals and sublimating chemicals for transition detection. Crossflow vortices were observed for one flight condition. Results of analyzed data for various flight-test conditions are presented.

Author

# AERONAUTICAL ENGINEERING

*A Continuing Bibliography (Suppl. 253)*

JUNE 1990

01

## AERONAUTICS (GENERAL)

**A90-23917#**

### **MANY MEANS TO NASP**

RICHARD DEMEIS (Aerospace America, Washington, DC)  
Aerospace America (ISSN 0740-722X), vol. 28, Feb. 1990, p. 32-34,  
36, 38.

Copyright

The NASP target to fly 25 times the speed of sound and demonstrate single-stage-to-orbit operation, will bring together for the first time in a manned vehicle different advanced technologies: propulsion, materials, integrated aero-thermodynamics, and controls. Unmanned vehicles are also under consideration as backup options. A new concept, the Flying Wind Tunnel (FWT), would gather data for future hypersonic air-breathing engines as well as do exhaust flow expansion measurements and CFD validations. Launched from a B-52 an FWT mission could range up to 750 miles, and upwards of 30 sec of desired high Mach test time would be produced in flight, as well as high dynamic pressure and heat transfer conditions. Flight testing is essential for controlling and validating the aerodynamics and propulsion of a hypersonic vehicle to obtain the right airflow sensors. It is pointed out that the techniques needed to pilot an SSTD aircraft from runway to orbit must ultimately be done with the manned X-30 itself.

R.E.P.

**A90-23934**

### **ROTORCRAFT ANALYTICAL IMPROVEMENT NEEDED TO REDUCE DEVELOPMENTAL RISK - THE 1989 ALEXANDER A. NIKOLSKY LECTURE**

CHARLES C. CRAWFORD, JR. (Georgia Institute of Technology,  
Atlanta) American Helicopter Society, Journal (ISSN 0002-8711),  
vol. 35, Jan. 1990, p. 3-22. refs

Copyright

The current status of theoretical models and analytical tools for the design of helicopters is surveyed, with a focus on the enhancements needed to avoid the costs of significant changes during the postdesign phase of aircraft development. Topics addressed include vibration predictions, rotor-load predictions, aerodynamic performance, cases where major design changes were required after flight tests, wind-tunnel testing, realistic weight estimates, power margins, and general analytical methods. Extensive diagrams, drawings, graphs, photographs, and tables are provided.

T.K.

**A90-24229**

### **MONITORING OF AIRCRAFT ASSEMBLY: OPTICAL AND LASER METHODS [KONTROL' SBORKI LETATEL'NYKH APPARATOV: OPTICHESKIE I LAZERNYE METODY]**

ALEKSANDR A. MITROFANOV Moscow, Izdatel'stvo  
Mashinostroenie, 1989, 208 p. In Russian. refs

Copyright

Optical and laser methods used for measuring linear and angular quantities during the assembly of helicopters and aircrafts are

reviewed. The discussion covers theoretical fundamentals of optical and laser measurements, the principal characteristics of laser measuring instruments, and safety precautions in working with lasers. Some specific measuring procedures using optical and laser instruments are described.

V.L.

**A90-24231**

### **AUTOMATIC TESTING IN AIRCRAFT BUILDING**

[AVTOMATIZIROVANNYE ISPYTANIYA V AVIASTROENII]

RAVIL' I. ADGAMOV, MANSUR M. BERKHEEV, IL'DUS A.  
ZALIAEV, IU. V. KOZHEVNIKOV, V. L. KRASNYKH et al. Moscow,  
Izdatel'stvo Mashinostroenie, 1989, 232 p. In Russian. refs

Copyright

The principal requirements for automatic testing systems used in the design, development, manufacture, operation, and maintenance and repair of aircraft equipment are reviewed. The discussion covers the hardware components of automatic testing systems and software support; test planning and preparation; measurements and evaluation of test results; diagnostic algorithms and calculation of corrections, and a generalized algorithm of automatic testing system operation. Attention is also given to the computer-aided design of automatic testing systems.

V.L.

**A90-24265**

### **STEALTH - DECEPTION, EVASION, AND CONCEALMENT IN THE AIR**

DOUG RICHARDSON New York, Orion Books, 1989, 187 p.

Copyright

A comprehensive treatment is presented of radar cross-section (RCS) and infrared signature (IRS) reduction 'stealth' methods for military aircraft. RCS, whose minimization is critical in the case of large bombers such as the B-1B and B-2, can be approached through careful contouring of aerodynamic surfaces to minimize reflectivity and the incorporation of various nonmetallic radar-absorbent surfacing materials in leading edges and engine inlets. IRS, which is greatest in supersonic aircraft both due to exhaust heat emissions and aerodynamic friction, may be reduced in subsonic aircraft such as the B-2 by the dilution of the exhaust gases with an additional airflow.

O.C.

**A90-24280**

### **CARING FOR THE ELDERLY JET**

J. R. WILSON and BRON REK Interavia (ISSN 0020-5168), vol.  
44, Dec. 1989, p. 1177-1179.

Copyright

Three task forces were set up in 1988 to examine the condition of various types of elderly jet, and recommend maintenance and repair actions needed to keep these aircraft in safe condition. Basically, the task forces have assembled the many service bulletins already issued by the manufacturers and added a new concept: instead of inspecting critical components and leaving them alone if they seem to be in good condition, or repairing them if they are damaged, such parts will have to be replaced after they have undergone a fixed number of cycles. This major change has been made mandatory by the FAA. The new philosophy may save costs in some cases, in that the automatic replacement of a part may be cheaper than indefinite repeated inspections and repairs. But, overall, maintenance cost will increase for older aircraft as a result of FAA actions.

R.E.P.

**A90-24291**

**COMPOSITES FOR AERONAUTICAL STRUCTURES  
[COMPOSITES POUR STRUCTURES AERONAUTIQUES]**

J. L. BOUNIE (Aerospatiale, Toulouse, France) *Revue Française de Mécanique* (ISSN 0373-6601), no. 2, 1989, p. 209-218. In French.

Copyright

The full set of composite parts used on aircraft is quite diversified, as are the manufacturing technologies and the types of materials implemented. Hybrid, monolithic, sandwich, bonded, or riveted structures may be used. Besides leading parts such as mobile or airfoil surfaces, there are many others that are more and more extensively applied on recent aircraft (fairings, floors, accommodations, etc.). For every specified application, whatever its advantages or drawbacks, the following parameters should always be accounted for: (1) environment (temperature, moisture, static electricity, lightning, and coupling processes); (2) structural features (holes, fasteners, and load-transferring parts); and (3) specific residual strength (to damage and fatigue). Following a short survey of the main implementations on large civil transport aircraft, particular attention is given to the ATR72 carbon wing box.

Author

**A90-24685**

**ENTRAPMENT PLATING OF ABRASIVE PARTICLES FOR JET  
ENGINE CLEARANCE CONTROL**

MARK SINGLETON, ED FARMER, and GARY PARKS (GE Aircraft Engines, Cincinnati, OH) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 15 p.*

(SAE PAPER 890918) Copyright

The application of an abrasive coating to the tip of a rotating member in order to minimize tip recession upon contact with a static component allows turbine (and/or compressor) efficiency to be retained via the resultant reduction in tip clearance and associated leakage. Entrapment electroplating of abrasive particles provides the most flexible and controllable means of applying such coatings to engine components, but is somewhat limited by component geometry. Techniques are described for the application of entrapment plated abrasive coatings to the tips of high pressure turbine blades and turbine seal teeth.

Author

**A90-24689**

**ELECTROMAGNETIC DENT REMOVAL FOR AIRCRAFT  
REPAIR**

TOM ROSEBERRY (Douglas Aircraft Co., Long Beach, CA) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 13 p.*

(SAE PAPER 890923) Copyright

This paper describes the operating principles, capabilities, limitations, and the state of development of an electromagnetic dent removal (EDR) system for aircraft repair. The EDR system consists of two primary components: the power source which contains the capacitor banks and electrical controls, and the flux concentrator coil holder with the coil which generates the magnetic fields. It is shown that EDR repairs can be accomplished in a fraction of the time required by conventional repair processes and these repairs are superior to those accomplished by other processes.

I.S.

**A90-24690**

**MANUFACTURING AND HANDLING TECHNIQUES USED IN  
THE ASSEMBLY OF POLISHED COMMERCIAL AIRCRAFT**

DELL F. SKLUZAK and JERRY T. WHICKER (Aluminum Company of America, Alcoa Center, PA) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 9 p.*

(SAE PAPER 890925) Copyright

Production and handling techniques used in the assembly of commercial aircraft with polished aluminum fuselage skins are discussed. Various procedures used to produce and protect the valuable skin materials of the exterior panels from the stage of manufacturing to the delivery of fully assembled aircraft are

described. Special attention is given to the handling equipment, protective coatings, the fabrication of aircraft components, riveting/rivet tape protection, the aluminum sheet orientation, and the repair of minor irregularities on the skin material that result from normal processing.

I.S.

**A90-24693**

**MICROSTRUCTURAL EFFECTS OF PLASTIC MEDIA  
BLASTING ON GRAPHITE EPOXY COMPOSITES**

JOSEPH KOZOL, STEVEN THOMAN, and KENNETH CLARK (U.S. Navy, Naval Air Development Center, Warminster, PA) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 23 p. refs* (SAE PAPER 890928) Copyright

The Naval Air Development Center is conducting a program to characterize the effects of Plastic Media Blasting (PMB) as a coating removal process. The objective of this study was to determine the effects of PMB on the microstructure of graphite/epoxy (Gr/Ep) materials. In the first phase of the program, screening tests were performed to evaluate and optimize the critical operating parameters. For Phase II of the program, optimized parameters were chosen from the Phase I test results and the effects of four repeat paint and blast cycles were determined on graphite/epoxy panels. After four repeat blast cycles, several of the conditions caused minimal visible damage.

Author

**A90-24694**

**THE SELECTION AND PERFORMANCE OF THERMAL  
SPRAYED ABRADABLE SEAL COATINGS FOR GAS TURBINE  
ENGINES**

EDWARD R. NOVINSKI (Perkin-Elmer Corp., Metco Div., Westbury, NY) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 6 p. refs*

(SAE PAPER 890929) Copyright

Criteria used in designing thermal sprayed abrasible seal coatings for gas turbine engines are discussed. These include the conditions of being readily abrasible and yet being resistable to particle impact erosion from engine-ingested abrasive dust at high gas velocities. Other important criteria include temperature stability, inertness, and consistency. The paper describes the classes of abrasible seal materials; the characterization of thermal sprayed abrasibles; the current coating materials' temperature, erosion, and abrasibility performance; and current research in thermal sprayed abrasible coating materials.

I.S.

**A90-24699**

**AUTOMATED AIRCRAFT PAINT STRIP CELL**

THOMAS EDWARD BYERS (USAF, Ogden Air Logistics Command, Ogden AFB, UT) and ROBERT PAULI (Pauli and Griffin Co., Vacaville, CA) *SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 12 p.*

(Contract FY1457-85-O-5036; F33615-86-C-5044)

(SAE PAPER 890936) Copyright

The development of an automated/robotic stripping process for F-4 and F-16 aircraft is discussed. The selection and optimization processes involved the evaluation of various stripping methods prior to selecting the plastic media blast procedure. The design and requirements for the Robotic Paint Stripper Cell (RPSC) and the testing of a prototype are described. The installation and verification phase of the project is examined. Diagrams of the RPSC are provided.

I.F.

**A90-25221**

**DESIGN AND FABRICATION OF THE CARBON FIBER/EPOXY  
A-320 HORIZONTAL TAILPLANE**

A. BARRIO CARDABA, F. RODRIGUEZ LENCE, and J. SANCHEZ GOMEZ (Construcciones Aeronauticas, S.A., Madrid, Spain) *SAMPE Journal* (ISSN 0091-1062), vol. 26, Jan.-Feb. 1990, p. 9-13.

Copyright

The structural and manufacturing benefits of carbon fiber/epoxy

advanced composite materials have made them the standard for commercial jetliner secondary structures. An effort has been made to extend the use of these materials to highly loaded primary structure with the production of the A-320 Horizontal Tailplane (HTP). The basic material for this component is Hexcel F-593 modified epoxy. Innovative designs provide 15 percent weight savings compared to a conventional aluminum structure. Manufacturing techniques centered around a combination of aluminum and carbon fiber epoxy curing tools have been applied to produce high quality components. Author

**N90-16707#** RAND Corp., Santa Monica, CA.

**THE USE OF PROTOTYPES IN SELECTED FOREIGN FIGHTER AIRCRAFT DEVELOPMENT PROGRAMS: RAFALE, EAP, LAVI, AND GRIPEN Interim Report**

MARK A. LORELL and DONNA KIM HOFFMAN Sep. 1989 79 p

(Contract MDA903-85-C-0030)

(AD-A214500; RAND/R-3687-P/L; ISBN-0-8330-0970-2) Avail:

NTIS HC A05/MF A01 CSCL 01/3

This report surveys and compares the approaches to prototyping adopted by four countries--Great Britain, France, Israel, and Sweden--during the development of similar new fighter/attack aircraft. It is based primarily on information gathered during interviews and briefings conducted in 1987 with senior government and industry officials of those countries. Basic fighter airframe risks and uncertainties to warrant the manufacture and flight testing of an austere airframe prototype before full-scale development (FSD). However, avionics development and integration are becoming areas of increasingly high technological complexity, uncertainty, and risk. Effective development and adequate testing and integration may be possible only with the help of sophisticated avionics ground labs and with fully missionized prototypes that are essentially pre-production FSD engineering test articles. A combination of both pre-FSD austere prototyping and missionized prototyping may be required to meet the challenges arising in the acquisition environment of the late 1980s. GRA

**N90-16708#** Southwest Research Inst., San Antonio, TX.

**INSPECTION DEVELOPMENT FOR T-37 WING SPAR CAP LUG Final Report, 1 Oct. 1988 - 30 Jun. 1989**

JAY L. FISHER, GARY L. BURKHARDT, STEPHEN N. ROWLAND, JR., JOHN H. FITZGERALD, and ROBERT J. DEXTER Jun. 1989 58 p

(Contract DLA900-84-C-0910)

(AD-A214826; SRI-17-7958-851; SAALC/MMEP-88-02) Avail:

NTIS HC A04/MF A01 CSCL 14/2

The purpose of this project was to develop an eddy current nondestructive inspection technique and procedure for the fatigue-critical location on the lower cap lug fillet of the T-37 wing spar, and to develop and conduct an inspection reliability program to quantify the inspection capability. The inspection capability goal was to demonstrate a probability of detection of 90 percent with a 95 percent confidence level for 0.050 inch radius fatigue cracks in the critical region of the lug. A hand-operated mechanical probe manipulator was developed to ensure uniform inspection results. A set of test specimens with fatigue cracks was fabricated for the reliability study. All of the goals were met or exceeded in the program. GRA

## 02

### AERODYNAMICS

Includes aerodynamics of bodies, combinations, wings, rotors, and control surfaces; and internal flow in ducts and turbomachinery.

**A90-23752#**

**VISCOUS FLOW CALCULATIONS IN TURBOMACHINERY CHANNELS**

FRANCESCO MARTELLI and VITTORIO MICHELASSI (Firenze, Universita, Florence, Italy) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by MPI. refs (ASME PAPER 89-GT-5)

An implicit procedure based on the artificial compressibility formulation is presented for the numerical solution of the two-dimensional incompressible steady Navier-Stokes equations in the presence of large separated regions. Turbulence effects are accounted for by the Chien (1982) low Reynolds number form of the K-epsilon turbulence model and the Baldwin-Lomax algebraic expression for turbulent viscosity. Preliminary tests were carried out in a laminar flow regime to check the accuracy and stability of the method in two-dimensional and cylindrical axisymmetric flow configurations. After testing in laminar and turbulent flow regimes and comparing the two turbulence models, the code was successfully applied to an actual gas turbine diffuser at low Mach numbers. Author

**A90-23753#**

**MEASUREMENT AND CALCULATION OF THE THREE-DIMENSIONAL FLOW IN AXIAL COMPRESSOR STATORS, WITH AND WITHOUT END-BENDS**

C. J. ROBINSON, J. D. NORTHALL (Rolls-Royce, PLC, Derby, England), and C. W. R. MCFARLANE (Cranfield Institute of Technology, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research sponsored by Rolls-Royce, PLC and Department of Trade and Industry. refs (ASME PAPER 89-GT-6)

This paper presents results from tests of two stators, one conventional and one with end-bends, operating at low speed in the buried stage environment of a Cranfield, 4-stage research compressor. The test results are compared with predictions from the Moore (1985) Elliptic Flow Program which solves the full, three-dimensional, Navier-Stokes equations with a pressure correction algorithm. The calculation results capture the essential physics of the viscous flow in these two bladerows. Author

**A90-23757#**

**STUDY OF VARIOUS FACTORS AFFECTING SECONDARY LOSS VORTICES DOWNSTREAM A STRAIGHT TURBINE CASCADE**

A. MOBARAK, M. G. KHALAFALLAH (Cairo, University, Giza, Egypt), H. A. HEIKAL (Helwan University, Egypt), and A. M. OSMAN (Zagazig University, Egypt) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs (ASME PAPER 89-GT-12)

An experimental investigation is carried out to study the effect of inlet boundary layer thickness, aspect ratio, and exit Mach number on the energy loss and on the behavior of secondary vortices downstream of a straight turbine cascade with blades at an 82 deg turning angle. Correlations were deduced which predict the cascade efficiency and the gross secondary loss coefficient as a function of the downstream distance. Author

**A90-23759#**

**A METHOD FOR CALCULATING AXIAL TURBOMACHINE END WALL TURBULENT BOUNDARY LAYERS**

SHUN KANG, FENGJUN LIU, and ZHONGQI WANG (Harbin Institute of Technology, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. Research supported by the National Natural Science Foundation. refs (ASME PAPER 89-GT-15)

The importance of endwall flow in axial turbomachines and the interactions of this behavior with overall performance is increasingly recognized. Here, the differential and integral equations of the endwall boundary layer are established in an orthogonal curvilinear coordinate system for relatively wide curve passages based on the concept of the S2 stream surface. Taking into account the fact that the blade force defect inside the endwall boundary

## 02 AERODYNAMICS

layer is correlated with the twist of S2 stream surface near the endwall, the values of the blade force defect is related to the degree of stream, surface skew. A theoretical formula for solving the defect values is developed, and closure relations for solving the boundary layer are presented. Predictions are made concerning the endwall boundary layer inside two guide vanes. C.D.

### A90-23760#

#### IMPROVEMENT OF 3D FULL-POTENTIAL METHOD AND COMPUTATION OF FLOWFIELD OF CAS COMPRESSOR ROTOR

JIALIN ZHANG (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. Research supported by the K. C. Wang Education Foundation. refs (ASME PAPER 89-GT-17)

A newly improved, three-dimensional, full-potential method for solving the flow in turbomachines is discussed. The method incorporates flow loss and viscous effect of flow near boundaries. The method is used to compute the three-dimensional flowfield in the compressor rotor of the Chinese Academy of Sciences (CAS) at 60 percent design rotational speed, and some results are presented. C.D.

### A90-23761#

#### INFLUENCE OF THE RADIAL COMPONENT OF TOTAL PRESSURE GRADIENT ON TIP CLEARANCE SECONDARY FLOW IN AXIAL COMPRESSORS

IAN N. MOYLE (U.S. Naval Postgraduate School, Monterey, CA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. Research supported by the U.S. Navy. refs (ASME PAPER 89-GT-19)

The interaction of tip leakage and the rotor passage secondary flow is examined. An analytical expression is developed which relates radial components of the total pressure gradient near the wall to the passage geometry, tip speed, skew, throughflow and wall skin friction coefficient. This expression provides a correlation with the differences observed in the passage secondary velocity patterns associated with tip clearance gaps in experimental compressors. The analysis is qualitatively supported by comparison with secondary flow velocity measurements from a small sample of published test data. Author

A90-23762\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

#### APPLICATION OF A LOWER-UPPER IMPLICIT SCHEME AND AN INTERACTIVE GRID GENERATION FOR TURBOMACHINERY FLOW FIELD SIMULATIONS

YUNG K. CHOO (NASA, Lewis Research Center, Cleveland, OH), WOO-YUNG SOH (NASA, Lewis Research Center; Sverdrup Technology, Inc., Cleveland, OH), and SEOKKWAN YOON (NASA, Ames Research Center; MCAT Institute, Moffett Field, CA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. refs (ASME PAPER 89-GT-20)

A finite-volume lower-upper (LU) implicit scheme is used to simulate an inviscid flow in a turbine cascade. This approximate factorization scheme requires only the inversion of sparse lower and upper triangular matrices, which can be done efficiently without extensive storage. As an implicit scheme it allows a large time step to reach the steady state. An interactive grid generation program (TURBO), which is being developed, is used to generate grids. This program uses the control point form of algebraic grid generation which uses a sparse collection of control points from which the shape and position of coordinate curves can be adjusted. A distinct advantage of TURBO compared with other grid generation programs is that it allows the easy change of local mesh structure without affecting the grid outside the domain of dependence. Sample grids are generated by TURBO for a compressor rotor blade and a turbine cascade. The turbine cascade flow is simulated

by using the LU implicit scheme on the grid generated by TURBO. Author

### A90-23763#

#### INVISCID CASCADE FLOW CALCULATIONS USING A MULTIGRID METHOD

A. A. ARNONE and S. S. STECCO (Firenze, Universita, Florence, Italy) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by MPI. refs (ASME PAPER 89-GT-22)

An accurate reliable and efficient computer code for inviscid cascade flow calculations has been developed and applied on sheared H-type grids. An additional wedge is added to blades with rounded trailing edges and care is taken to correctly capture the shock system when the outlet flow is supersonic. Comparison with experiments shows that the method can be applied to turbomachinery yielding good blade-to-blade predictions. Author

### A90-23766#

#### A PROPOSAL FOR OPTIMIZED DESIGN OF MULTISTAGE COMPRESSORS

RAFFAELE TUCCILLO (Napoli, Universita, Naples, Italy) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 15 p. Research supported by MPI. refs (ASME PAPER 89-GT-34)

The aim of the paper is to provide a methodology for optimum design of axial flow multistage compressors derived from a flow model, previously defined by the author, that takes into account the effects of several geometrical parameters on blade losses and on the growth of end-wall boundary layers and secondary vorticities. The optimization is performed by means of a 'Quasi-Newton' algorithm that controls an 'Augmented Lagrangian Function' with the objective of maximizing efficiency for assigned values of total to total head. The paper outlines the theoretical approach and the main practical feature of the methodology, the latter consisting of a performance optimization by imposing even slight variations to the geometry of an existing compressor. Author

### A90-23771#

#### ACCELERATED COMPUTATION OF VISCOUS, STEADY INCOMPRESSIBLE FLOWS

SEUNGSOO LEE and GEORGE S. DULIKRAVICH (Pennsylvania State University, University Park) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs (Contract AF-AFOSR-87-0121) (ASME PAPER 89-GT-45)

Based on an artificial compressibility method, the explicit Runge-Kutta time stepping finite difference algorithm was applied to steady, incompressible, Navier-Stokes equations. A two-dimensional analysis computer code in a generalized curvilinear coordinate system was developed and its accuracy has been compared to known numerical solutions. The algorithm has been accelerated using the new Distributed Minimal Residual (DMR) method, which allows each equation in the system to advance in time with its own optimal speed. The effectiveness of the DMR method was examined for a number of test cases. The accelerated algorithm offers substantial savings of the computing time. Author

### A90-23772#

#### OVERVIEW ON TEST CASES FOR COMPUTATION OF INTERNAL FLOWS IN TURBOMACHINES

LEONHARD FOTTNER (Muenchen, Universitaet der Bundeswehr, Neubiberg, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. (ASME PAPER 89-GT-46)

Aero engine component design and development makes increasing use of computer codes for flow field calculations, such as two- or three-dimensional flow fields and flow fields with strong

viscous effects. The accuracy of these calculation methods depends on the mathematical models and numerical schemes used to describe the physical reality. The proof of validity and the refinement of such methods depend on verification against relevant test cases, primarily experimental test cases. The AGARD Propulsion and Energetics Panel established Working Group 18 to specify relevant reference test cases to serve as validation bases for new methods, but also as check for existing production codes. The present paper gives an overview on the results of the Working Group and briefly describes the different test cases. These test cases refer to analytical and experimental test cases for steady flow in linear compressor and turbine cascades, single blade rows, single and multistage axial compressors and turbines and ducts. In addition, suggestions for future tests designed to reduce the limitations are discussed. Author

#### A90-23773#

##### SECONDARY LOSS GENERATION IN A LINEAR CASCADE OF HIGH-TURNING TURBINE BLADES

S. HARRISON (Cambridge, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. Research supported by the Ministry of Defence Procurement Executive and SERC. refs (ASME PAPER 89-GT-47)

Flow through a linear cascade of high-turning, low aspect ratio turbine blades has been measured in great detail at five planes within the cascade and two downstream in order to trace the generation of stagnation pressure loss in the passage. Five-hole probes were used in the main flow but as it is important to resolve the boundary layers accurately three-hole and single flattened probes were used near the end wall and blade surfaces respectively. End wall shear stresses have been measured using a hot-film probe and an oil-drop viscosity balance technique. Numerical predictions and simple aerodynamic models are used in conjunction with the experimental data to estimate the relative importance of different loss mechanisms, including boundary layer shear stresses and mixing processes. Author

#### A90-23774#

##### 3D MEAN-STREAM-LINE METHOD - A NEW ENGINEERING APPROACH TO THE INVERSE PROBLEM OF 3D CASCADE

YIFANG GONG and RUIXIAN CAI (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs (ASME PAPER 89-GT-48)

The Mean-Stream-Line Method proposed by Wu and Brown (1952) for two-dimensional cascades is developed and extended to solve the three-dimensional inverse problem of turbomachine flow. Equations suitable to this case are derived and well-posed design conditions are discussed in the context of the annular wall constraint for turbomachines. Results from a computer code programmed for this method compare well with three-dimensional, incompressible potential analytical solutions from Cai et al. (1984). Results from the present method are also compared with those from the conventional, three-dimensional potential function method. The present method is much simpler and faster than all other available methods. Some suggestions for solving direct and hybrid problems are also made. C.D.

#### A90-23777#

##### COMPRESSOR BLADE BOUNDARY LAYERS. II - MEASUREMENTS WITH INCIDENT WAKES

Y. DONG and N. A. CUMPTSY (Cambridge, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by Rolls-Royce, PLC. (ASME PAPER 89-GT-51)

A supercritical compressor blade has been tested at design incidence at a low-speed, large-scale cascade wind tunnel with incident wakes from upstream. The wake created a turbulent patch where it impinged on the blade; this patch quickly became self-sustaining, like a turbulent spot found in a transitional boundary

layer. The patch underwent rapid transition when it arrived at the originally laminar boundary layer on the blade surface. The laminar separation bubble was periodically unsteady when wakes were present, and disappeared if the wake initiated transition before the laminar flow could separate. The wake interaction with the boundary layer also resulted in a stabilizing effect on the laminar boundary layer behind a turbulent patch. This prolonged the extent of laminar flow seen on the blade surface compared with the case without wakes. The presence of wakes therefore did not have very significant effect on the overall development of the surface boundary layers. C.D.

#### A90-23778#

##### FLOW IN A CENTRIFUGAL FAN OF THE SQUIRREL CAGE TYPE

R. J. KIND (Carleton University, Ottawa, Canada) and M. G. TOBIN (GasTOPS, Ltd., Gloucester, Canada) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. Research supported by NSERC. refs (ASME PAPER 89-GT-52)

This paper presents the results of performance measurements and detailed measurements of the mean flow field at rotor inlet and rotor exit in three squirrel cage fan configurations. The flow-field measurements were taken with a five-hole probe and yield total pressure, static pressure and the three components of velocity. Measurements were taken for two casing throat areas and for two different rotors. For each configuration the flow field was measured for flow rates below, near and above the best-efficiency point. Flow patterns are complex and there is reverse flow through the rotor blading even at the best-efficiency operating condition. Although complex, the main features of flow behavior can be understood. They were common to all three fan configurations. Author

#### A90-23779#

##### BLADE SWEEP FOR LOW-SPEED AXIAL FANS

TERRY WRIGHT and WILLIAM E. SIMMONS (Alabama, University, Birmingham) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs (ASME PAPER 89-GT-53)

The available literature on aerodynamic and acoustic properties of axial fans with swept blades is presented and discussed, emphasizing noise mechanisms and the influence of high-intensity inlet turbulence on 'excess' noise. Computer codes are developed based on the literature and used to design three prototype fans. One is a baseline fan with blade stacking lines radially oriented, and two are fans with swept blades of increasing forward sweep. Aerodynamic testing of the fan performance validates the design procedure. Noise testing of the fans results in an average noise reduction for the swept-bladed fans of about 7 dBA overall and a reduction of pure tone noise at blade-pass frequency of about 10 dB compared to the zero-sweep baseline model. C.D.

#### A90-23781#

##### DEVELOPMENT OF THE TIP-LEAKAGE FLOW DOWNSTREAM OF A PLANAR CASCADE OF TURBINE BLADES - VORTICITY FIELD

M. YARAS and S. A. SJOLANDER (Carleton University, Ottawa, Canada) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by Pratt and Whitney Canada. refs (Contract NSERC-A-1671) (ASME PAPER 89-GT-55)

The paper presents detailed measurements of the tip-leakage flow emerging from a planar cascade of turbine blades. Four clearances of from 1.5 to 5.5 percent of the blade chord are considered. Measurements were made at the trailing edge plane, and at two main planes 1.0 and 1.56 axial chord lengths downstream of the cascade. The results give insight into several aspects of the leakage flow including: the size and strength of the leakage vortex in relation to the size of the tip gap and the bound circulation of the blade; and the evolution of the components of vorticity as the vortex diffuses laterally downstream of the blade



row. The vortex was found to have largely completed its roll-up into a nearly axisymmetric structure even at the trailing edge of the cascade. As a result, it was found that the vortex could be modeled surprisingly well with a simple model based on the diffusion of a line vortex. Author

### A90-23782#

#### TIP LEAKAGE LOSSES IN A LINEAR TURBINE CASCADE

PETER T. DISHART and JOHN MOORE (Virginia Polytechnic Institute and State University, Blacksburg) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 12 p. Research supported by Rolls-Royce, PLC. refs (ASME PAPER 89-GT-56)

An investigation of tip leakage flow and its effects on loss production was performed on a large scale linear turbine cascade having a tip gap measuring 2.1 percent of the blade height. The flow exiting the tip gap was measured to determine the losses incurred within the tip gap and the secondary kinetic energy due to tip leakage. Additional measurements, 40 percent of an axial chord downstream of the blade trailing edges, showed the development of the leakage flow and the overall cascade losses. At the downstream location, the additional loss due to tip leakage was found to be the sum of the measured loss at the tip gap exit plane and the amount of tip gap secondary kinetic energy which had been dissipated by that downstream location. Author

### A90-23784#

#### SELF-EXCITED OSCILLATION OF TRANSONIC FLOW AROUND AN AIRFOIL IN TWO-DIMENSIONAL CHANNEL

KAZUOMI YAMAMOTO (National Aerospace Laboratory, Chofu, Japan) and YOSHIMICHI TANIDA (Tokyo, University, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. refs (ASME PAPER 89-GT-58)

A self-excited oscillation of transonic flow in a simplified cascade model was investigated experimentally, theoretically and numerically. The measurements of the shock wave and wave motions, and unsteady static pressure field predict a closed loop mechanism, in which the pressure disturbance that is generated by the oscillation of boundary layer separation propagates upstream in the main flow and forces the shock wave to oscillate; then the shock oscillation disturbs the boundary layer separation again. A one-dimensional analysis confirms that the self-excited oscillation occurs in the proposed mechanism. Finally, a numerical simulation of the Navier-Stokes equations reveals the unsteady flow structure of the reversed flow region around the trailing edge, which induces the large flow separation to bring about the anti-phase oscillation. Author

### A90-23786#

#### STALL INCEPTION IN AXIAL COMPRESSORS

N. M. MCDOUGALL, N. A. CUMPSTY, and T. P. HYNES (Cambridge, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by Rolls-Royce, PLC and SERC. refs

(ASME PAPER 89-GT-63)

Detailed measurements have been made of the transient stalling process in an axial compressor state. The state is of high hub-casing ratio and stall is initiated in the rotor. If the rotor tip clearance is small stall inception occurs at the hub, but at clearances typical for a multistage compressor the inception is at the tip. The crucial quantity in both cases is the blockage caused by the endwall boundary layer. Prior to stall disturbances rotate around the inlet flow in sympathy with rotating variations in the endwall blockage; these can persist for some time prior to stall, rising and falling in amplitude before the final increase which occurs as the compressor stalls. Author

### A90-23787#

#### EFFECTS OF ENDWALL SUCTION AND BLOWING ON COMPRESSOR STABILITY ENHANCEMENT

N. K. W. LEE and E. M. GREITZER (MIT, Cambridge, MA) ASME,

Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 13 p. Research supported by General Motors Corp. and USAF. refs (ASME PAPER 89-GT-64)

An experimental investigation was carried out to examine the effects on stall margin of flow injection into, and flow removal out of, the endwall region of an axial compressor blade row. A primary objective of the investigation was clarification of the mechanism by which casing treatment (which involves both removal and injection) suppresses stall in turbomachines. To simulate the relative motion between blade and treatment, the injection and removal took place through a slotted hub rotating beneath a cantilevered stator row. Overall performance data and detailed (time-averaged) flowfield measurements were obtained. Flow injection and removal both increased the stalling pressure rise, but neither was as effective as the wall treatment. Removal of high blockage flow is thus not the sole reason for the observed stall margin improvement in casing or hub treatment, as injection can also contribute significantly to stall suppression. The results also indicate that the increase in stall pressure rise with injection is linked to the streamwise momentum of the injected flow, and it is suggested that this should be the focus of further studies. Author

### A90-23788#

#### INLET SKEW AND THE GROWTH OF SECONDARY LOSSES AND VORTICITY IN A TURBINE CASCADE

J. A. WALSH (Logica Space and Defence Systems, Ltd., London, England) and D. G. GREGORY-SMITH (Durham, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by the Ministry of Defence Procurement Executive, Rolls-Royce, PLC, and SERC. refs (ASME PAPER 89-GT-65)

This paper presents results of an experimental investigation into the effects of inlet skew on the flowfield of a large scale axial flow turbine cascade. The results are presented in terms of the development of the streamwise vorticity since, in classical terms, the streamwise vorticity generates the transverse velocity components that cause the generation of the secondary losses. Inlet skew is shown to have a profound effect on the distribution and magnitude of the generated losses. A number of correlations for the secondary losses are compared with the measured values and it is shown that the correlations are not adequate for accurate loss prediction purposes. Author

### A90-23789#

#### APPLICATION OF LOW-SOLIDITY CASCADE DIFFUSER TO TRANSONIC CENTRIFUGAL COMPRESSOR

H. HAYAMI (Kyushu University, Kasuga, Japan), Y. SENOO (Miura Co., Ltd., Matsuyama, Japan), and K. UTSUNOMIYA (Mitsubishi Kasei, Ltd., Yokohama, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p.

(ASME PAPER 89-GT-66)

Low-solidity circular cascades, conformally transformed from high-stagger linear cascades of double-circular-arc vanes with solidity 0.69, were used as a part of the diffuser system of a transonic centrifugal compressor. Performance test results were compared with data of the same compressor with a vaneless diffuser. Good compressor performance, a wider flow range as well as a higher pressure ratio and a higher efficiency, superior to those with a vaneless diffuser, where the flow range was limited by choke of the impeller, were demonstrated. The test circular cascade diffusers demonstrated a good pressure recovery over a wide range of flow angles, even when the inflow Mach number to the cascade was over unity. Author

### A90-23790#

#### MACH NUMBER EFFECTS ON SECONDARY FLOW DEVELOPMENT DOWNSTREAM OF A TURBINE CASCADE

ANTONIO PERDICHIZZI (Brescia, Università, Italy) ASME, Gas

Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. refs  
(ASME PAPER 89-GT-67)

The results of an investigation of the three-dimensional flow downstream of a transonic turbine cascade are presented. The results are presented in terms of local loss coefficient, vorticity, and secondary velocity plots; these plots give a detailed picture of the secondary flow development downstream of the cascade and show how flow compressibility influences the vortex configuration. As Mach number increases, the passage vortex is found to migrate toward the endwall and secondary flow effects are more confined in the endwall region. The pitchwise mass averaged loss and flow angle distributions along the blade height appear to be affected by the expansion ratio; at high Mach number both underturning and overturning angles are found to be smaller than in low velocity flows. Overall losses, vorticity, and secondary kinetic energy versus Mach number are also presented and discussed. Author

#### A90-23794#

##### AN APPROXIMATE 3-D AERODYNAMIC DESIGN METHOD FOR CENTRIFUGAL IMPELLER BLADES

XIAOLU ZHAO and LISEN QIN (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. refs  
(ASME PAPER 89-GT-73)

The Mean Stream Surface Method has been incorporated into a CAD-CAM system for centrifugal compressor impeller blading design and manufacture. After specifying an S(2m) indirect solution for blade surfaces, a Taylor series expansion is employed to generate the blade geometry on the basis of straight-line elements. The fluid dynamics characteristics across the blade passages are simultaneously determined. A designer can accordingly revise the distributions of angular momentum along the shroud and hub, which are associated with blade loading to obtain satisfactory velocities along blade surfaces. O.C.

#### A90-23797#

##### THREE-DIMENSIONAL SEPARATED FLOW FIELD IN THE ENDWALL REGION OF AN ANNULAR COMPRESSOR CASCADE IN THE PRESENCE OF ROTOR-STATOR INTERACTION. I - QUASI-STEADY FLOW FIELD AND COMPARISON WITH STEADY-STATE DATA

H. D. SCHULZ, H. E. GALLUS, and B. LAKSHMINARAYANA (Aachen, Rheinisch-Westfaelische Technische Hochschule, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by DFG and NSF. refs  
(ASME PAPER 89-GT-76)

An experimental study of three-dimensional flow field in an annular compressor cascade with an upstream rotor has been carried out at four different incidences to the stator blade. Blade boundary layers and the three-dimensional flow field at the exit are surveyed using a hot wire sensor and a five hole probe, respectively. The data on the blade boundary layer, passage flow and separated corner flow is presented. The upstream rotor wake has a major influence on the transition, laminar separation bubble, extent of wall/corner flow separation, aerodynamic losses, secondary flow and three-dimensional flow inside the passage. Detailed interpretation of the effects of upstream wakes on the entire passage flow is presented and compared with the data in the absence of a rotor. Author

#### A90-23798#

##### THREE-DIMENSIONAL SEPARATED FLOW FIELD IN THE ENDWALL REGION OF AN ANNULAR COMPRESSOR CASCADE IN THE PRESENCE OF ROTOR-STATOR INTERACTION. II - UNSTEADY FLOW AND PRESSURE FIELD

H. D. SCHULZ, H. E. GALLUS, and B. LAKSHMINARAYANA (Aachen, Rheinisch-Westfaelische Technische Hochschule, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine

Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by DFG and NSF. refs  
(ASME PAPER 89-GT-77)

An experimental study of the unsteady three-dimensional flow and pressure field in an annular compressor cascade with an upstream rotor has been carried out at several incidences to the stator blade. The distribution of the unsteady pressures at the blade surfaces are measured using fast response Kulite sensors. The unsteady blade boundary layers and the passage flow is measured with a hot wire sensor. Detailed interpretation of the magnitude of unsteady pressure, phase angle differences, unsteady blade boundary layers, wake transport through the stator passage is presented and analyzed in the paper. The unsteady pressures are found to be dominant near the blade leading edge. Substantially higher pressure fluctuations occur in this region as well as on the edge of the corner flow separation region. Author

#### A90-23800\*# Purdue Univ., West Lafayette, IN.

##### COMPARISON OF STEADY AND UNSTEADY SECONDARY FLOWS IN A TURBINE STATOR CASCADE

GREGORY J. HEBERT and WILLIAM G. TIEDERMAN (Purdue University, West Lafayette, IN) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by USAF and NASA. refs  
(Contract N00014-87-G-0040)  
(ASME PAPER 89-GT-79)

The effect of periodic rotor wakes on the secondary flow structure in a turbine stator cascade was investigated. A mechanism simulated the wakes shed from rotor blades by passing cylindrical rods across the inlet to a linear cascade installed in a recirculating water flow loop. Velocity measurements showed a passage vortex, similar to that seen in steady flow, during the time associated with undisturbed fluid. However, as the rotor wake passed through the blade row, a large crossflow toward the suction surface was observed in the midspan region. This caused the development of two large areas of circulation between the midspan and endwall regions, significantly distorting and weakening the passage vortices. Author

#### A90-23829#

##### VISCOUS FLOW IN A CONTROLLED DIFFUSION COMPRESSOR CASCADE WITH INCREASING INCIDENCE

Y. ELAZAR and R. P. SHREEVE (U.S. Naval Postgraduate School, Monterey, CA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by the U.S. Navy. refs  
(ASME PAPER 89-GT-131)

A detailed two-component LDV mapping of the flow through a controlled diffusion compressor cascade at low Mach number (0.25) and Reynolds number of about  $7 \times 10^5$  to the 5th, at three inlet air angles from design to near stall, is reported. It was found that the suction side boundary layer reattached turbulent after a laminar separation bubble, and remained attached to the trailing edge even at the highest incidence, at which losses were 3 to 4 times the minimum value for the geometry. Boundary layer thickness increased to fill 20 percent of the blade passage at the highest incidence. Results for pressure-side boundary layer and near wake are also summarized. Author

#### A90-23837#

##### THREE-DIMENSIONAL SOLUTIONS FOR INVISCID INCOMPRESSIBLE FLOW IN TURBOMACHINES

S. ABDALLAH and C. F. SMITH (Pennsylvania State University, State College) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. Research supported by the U.S. Navy. refs  
(ASME PAPER 89-GT-140)

Three-dimensional solutions are obtained for the inviscid incompressible Euler equations using the primitive variable approach. In particular, the pressure Poisson equation approach using a non-staggered grid is considered. In this approach, the velocity field is calculated from the unsteady momentum equation by marching in time. The governing equations are solved in general

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curvilinear coordinates using non-staggered grids. The numerical results are then compared with experimental data of three turbomachinery rotors. The three rotor blades have been designed to have similar loading distributions but different amounts of dihedral. It is concluded that, in general, predicted trends in the radial variation of velocity and pressure are consistent with the differences in the geometries of each rotor. R.E.P.

### A90-23840#

#### THREE-DIMENSIONAL RELIEF IN TURBOMACHINERY BLADING

A. R. WADIA and B. F. BEACHER (GE Aircraft Engines, Cincinnati, OH) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 14 p. refs (ASME PAPER 89-GT-151)

It is noted that to fully realize the performance gains accruing from improved endwall flows requires a detailed understanding of the complex flow structure in the endwall region. This study reports on 2D and 3D calculations of the flow within two axial flow compressor stators operating near their design points. Computational results of the 3D analysis reveal a significant 3D relief near the casing endwall absent in the 2D calculations. Both analytical and experimental results of an investigation of 3D relief in several compressor stators is presented. One implication of this study is that the designer can depend, to some extent, on radial velocities to adjust the spanwise flow distribution such that endwall leading edge loadings are acceptable, even with relatively conventional airfoil shapes. R.E.P.

A90-23841\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

#### SIMULATION OF THREE-DIMENSIONAL VISCOUS FLOW WITHIN A MULTISTAGE TURBINE

JOHN J. ADAMCZYK (NASA, Lewis Research Center, Cleveland, OH), MARK L. CELESTINA, TIM A. BEACH (NASA, Lewis Research Center; Sverdrup Technologies, Inc., Cleveland, OH), and MARK BARNETT (United Technologies Research Center, East Hartford, CT) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 13 p. Previously announced in STAR as N89-14238. refs (ASME PAPER 89-GT-152)

This work outlines a procedure for simulating the flow field within multistage turbomachinery which includes the effects of unsteadiness, compressibility, and viscosity. The associated modeling equations are the average passage equation system which governs the time-averaged flow field within a typical passage of a blade row embedded within a multistage configuration. The results from a simulation of a low aspect ratio stage and a one-half turbine will be presented and compared with experimental measurements. It will be shown that the secondary flow field generated by the rotor causes the aerodynamic performance of the downstream vane to be significantly different from that of an isolated blade row. Author

### A90-23844#

#### A NEW DESIGN METHOD FOR CENTRIFUGAL COMPRESSOR VANED DIFFUSERS

XIAOYAN HUANG, QINGHUAN WANG, and CHAO ZHANG (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. refs (ASME PAPER 89-GT-156)

A numerical technique has been developed for the design and flow analysis of centrifugal compressor vaned diffusers, using the streamline-extension method. Velocity and pressure distributions at design and off-design operating conditions are calculated by means of a time-dependent finite-difference scheme, using boundary-layer calculations. A comparison of the results thus obtained with experimental measurements indicates that agreement is satisfactory. O.C.

### A90-23845#

#### LDV MEASUREMENTS AND THE FLOW ANALYSIS IN THE VANELESS REGION OF A RADIAL INFLOW TURBINE

A. N. LAKSHMINARASIMHA, W. TABAKOFF (Cincinnati, University, OH), and A. METWALLY ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 12 p. refs (ASME PAPER 89-GT-157)

Detailed experimental measurement was carried out in the vaneless (vortex) region of a radial inflow turbine using a three component LDV. A viscous and incompressible axisymmetric computational code was developed to analyze the flow. The experimental and theoretical results were compared to obtain the degree of nonuniformity of the flow in the circumferential direction. Author

### A90-23846#

#### A METHOD OF PREDICTING THE ENERGY LOSSES IN VANELESS DIFFUSERS OF CENTRIFUGAL COMPRESSORS

HUASHU DOU (Beijing University of Aeronautics and Astronautics, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-158)

A new method for analyzing the features of flow losses in vaneless diffusers of centrifugal compressors is presented. Simplifying assumptions on the flow pattern are made, and the equations of the wall friction coefficient and the wall friction loss are derived using boundary layer theory. An equation for calculating the total flow loss except for the mixing loss is obtained by analyzing the flow behavior and the experimental data in the literature. Comparison with experimental results show that the method is feasible. Although the method is approximate, it is simpler than the usual ones and can be applied to engineering design for preliminary prediction of flow losses. C.D.

### A90-23847#

#### VERIFICATION OF AN IMPELLER DESIGN BY LASER MEASUREMENTS AND 3D-VISCOUS FLOW CALCULATIONS

H. KRAIN and W. HOFFMAN (DLR, Institut fuer Antriebstechnik, Cologne, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs (ASME PAPER 89-GT-159)

Laser measurements and three-dimensional viscous calculations were performed to verify the design of a 30 deg back-swept impeller with advanced blade geometry and high design rotor pressure ratio. The results point to a low velocity area inside the rotor that vanishes toward the exit resulting in comparatively smooth discharge velocity profiles. Author

### A90-23851#

#### THE INFLUENCE OF DIFFUSER VANE LEADING EDGE GEOMETRY ON THE PERFORMANCE OF A CENTRIFUGAL COMPRESSOR

W. W. CLEMENTS and D. W. ARTT (Belfast, Queen's University, Northern Ireland) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-163)

A series of experiments was carried out on two turbocharger compressors to determine the influence of pressure face angle, semi-vaneless space suction surface profile and diffuser leading edge radius ratio on stage performance. It was found that while compressor performance was virtually unaffected by changes in pressure face angle, performance was sensitive to changes in the semi-vaneless space suction surface profile. Straight wedge diffusers produced higher stage efficiencies than any diffuser with a concave suction surface profile between the leading edge and throat. Optimum stage performance was achieved with diffuser leading edge radius ratios between 1.06 and 1.10. Author

A90-23878#

**THE EXTENSION AND APPLICATION OF  
THREE-DIMENSIONAL TIME MARCHING ANALYSES TO  
INCOMPRESSIBLE TURBOMACHINERY FLOWS**

P. J. WALKER (Rolls-Royce, PLC, Derby, England) and W. N. DAWES (Cambridge, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs  
(ASME PAPER 89-GT-212)

Conventional time marching flow solvers perform poorly when integrating compressible flow equations at low Mach numbers levels. This is shown to be due to unfavorable interaction between long wavelength errors and the inflow and outflow boundaries. Chorin's method of artificial compressibility is adopted to extend the range of Denton's inviscid flow solver and Dawes' three-dimensional Navier-Stokes solver to zero Mach number flows. The paper makes a new contribution by showing how to systematically choose the artificial acoustic speed to optimize convergence rate with regard to the error wave-boundary interactions. Applications to a turbine rotor and generic water pump geometry are presented. Author

A90-23883#

**AERODYNAMIC AND HEAT TRANSFER MEASUREMENTS ON  
BLADING FOR A HIGH RIM-SPEED TRANSONIC TURBINE**

R. C. KINGCOMBE, S. P. HARASGAMA, N. P. LEVERSUCH, and E. T. WEDLAKE (Royal Aerospace Establishment, Propulsion Dept., Farnborough, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs  
(ASME PAPER 89-GT-228)

A high rim speed turbine, incorporating some 3-D features has been designed and tested at RAE Pyestock. There has been cold flow turbine testing, with overall performance measurements, rotor exit traversing as well as surface static pressure measurements on the vane and rotor. The vane has also been tested in annular cascade on the Isentropic Light Piston Cascade giving surface heat transfer measurements on the vanes and endwalls as well as aerodynamic information. The data have been used to compare with design predictions and the reasons for the differences observed, particularly on the rotor blade, are explored. Author

A90-23935

**MODELING OF SUBSONIC UNSTEADY AERODYNAMICS FOR  
ROTARY WING APPLICATIONS**

J. G. LEISHMAN (Maryland, University, College Park) American Helicopter Society, Journal (ISSN 0002-8711), vol. 35, Jan. 1990, p. 29-38. refs  
(Contract DAAG29-83-K-0002)  
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Some practical applications of two-dimensional subsonic indicial response functions are discussed. These indicial functions are used with the superposition principle to obtain the unsteady lift, drag, and pitching moment on an airfoil. Numerical procedures are presented to account for arbitrary motion of a rotor blade section, as well as encounters with gusts or vortices. These procedures are presented in both discrete-time and continuous-time forms, either of which are suitable for practical application to comprehensive rotary wing performance and aeroelasticity analyses. The formulation represents an economical and accurate bridge between incompressible quasi-steady aerodynamics and more elaborate computational methods. An extensive validation of the approach is conducted with experimental data and other theoretical results. Author

A90-23938

**ANALYTICAL APPROACH TO THE INDUCED FLOW OF A  
HELICOPTER ROTOR IN VERTICAL DESCENT**

SHI-CUN WANG (Georgia Institute of Technology, Atlanta) American Helicopter Society, Journal (ISSN 0002-8711), vol. 35, Jan. 1990, p. 92-98. refs  
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An analytical approach is developed for calculating the induced

flow of a helicopter rotor in the entire vertical descent regime, from the hovering state through the vortex-ring state to the turbulent windmill state. The key concept is that, instead of the conservation of circulation in an ideal flow, a linear decay of circulation of trailing vortices is assumed in the real wake; and the distance required for the circulation to decay to zero is assumed to be directly proportional to the transport velocity of trailing vortices. By applying classical vortex theory to the vortex model, a simple relation between induced velocity and descent velocity of the helicopter rotor has been obtained in the form of a pair of parametric equations. Author

A90-23978

**AERODYNAMIC DESIGN METHODS FOR TRANSONIC WINGS**

R. C. LOCK (City University, London, England) Aeronautical Journal (ISSN 0001-9240), vol. 94, Jan. 1990, p. 1-16. refs  
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A review is given of current methods in theoretical aerodynamics which are useful in the design of aircraft wings for subsonic and transonic speeds. Attention is first given to direct methods for calculating the flow over a given wing shape. In the design process, these can be used to obtain a rapid estimate of the effect of a specified change in wing shape. The most practical methods of this type make use of the viscous/inviscid interaction technique; some recent methods are described and examples are given of their use, both in two and three dimensions, including comparisons with experiment. Consideration is then given to inverse methods in which the shape is calculated explicitly, as a result of either specifying the surface pressure distribution on the wing, or requiring that some suitable 'target' function, usually the drag/lift ratio, shall be a minimum. At present, these methods are restricted to inviscid flow. Author

A90-23996

**THE EFFECT OF UNIFORM SPANWISE VORTICITY ON THE  
TWO-DIMENSIONAL FLOW THROUGH CASCADES**

D. N. ANDREW (Cambridge, University, England) Institution of Mechanical Engineers, Proceedings, Part C - Journal of Mechanical Engineering Science (ISSN 0954-4062), vol. 203, no. C6, 1989, p. 371-378. Research supported by SERC and CompAir Reavell, Ltd. refs  
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An inherent characteristic of the flow in regenerative turbomachines is the presence of a uniform vorticity in the blade-to-blade plane. Control volume arguments indicate that the effect of this spanwise component of vorticity is to modify the loading on the blades, and modified forms of the Zweifel aerodynamic loading coefficient and the Lieblein compressor diffusion factor are derived to account for this effect. A method for calculating two-dimensional flow through cascades with a uniform spanwise vorticity is described, and results are presented which illustrate the increase in loading and deviation due to the presence of the vorticity. Author

A90-24009#

**STABILITY ANALYSIS AND NUMERICAL EXPERIMENTS FOR  
VISCOUS-INVISCID INTERACTION IN TRANSONIC FLOW**

BAO GUO WANG (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) Journal of Engineering Thermophysics (ISSN 0253-231X), vol. 10, Nov. 1989, p. 379-382. In Chinese, with abstract in English.

The inviscid solution is obtained by the stream function method. For the attached or separated turbulent boundary layer, calculations are performed by improved Green and East's lag entrainment method. The two calculations are coupled by an algorithm which converges rapidly for attached flows and performs well for separated flows. The classical iteration, inverse iteration, and semi-inverse method are discussed. Author

A90-24048#

**SOME ASPECTS OF THE NUMERICAL MODELING OF  
SUPERSONIC FLOW PAST FLIGHT VEHICLES**

G. P. VOSKRESENSKII and A. V. ZABRODIN (AN SSSR, Institut

Prikladnoi Matematiki, Moscow, USSR) Uspekhi Mekhaniki - Advances in Mechanics (ISSN 0137-3722), vol. 12, no. 2, 1989, p. 99-119. In Russian. refs

Some problems associated with mathematical modeling in supersonic flow problems are briefly reviewed. In particular, attention is given to applications of mathematical modeling in aerodynamics; theoretical aspects of mathematical modeling and selection of a mathematical flow model; pressure data accuracy requirements in the analysis of aerodynamic characteristics; and mathematical problems involved in the development of computational algorithms. The discussion also covers estimation of the data volume and computational effort in problems of flow past flight vehicles. V.L.

**A90-24076**

**NONSYMMETRIC VORTEX BREAKDOWN AND AERODYNAMIC HYSTERESIS IN FLOW PAST A LOW-ASPECT-RATIO WING/FUSELAGE CONFIGURATION [NESIMMETRICHNOE RAZRUSHENIE VIKHREI I AERODINAMICHESKII GISTEREZIS PRI OBTEKANII KRYLA MALOGO UDLINENIIA S FIUZELIAZHEM]**

M. G. GOMAN, A. I. ZADOROZHNI, and A. N. KHRABROV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 1-7. In Russian. refs

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Results of a wind-tunnel visualization study of separated flow past a model of a delta wing with a conical fuselage are reported. In particular, attention is given to nonsymmetric vortex breakdown, which is observed for zero slip angle at large angles of attack, and to aerodynamic hysteresis due to changes in the slip angle. The effect of flow perturbation on the characteristics of separated flow past a body is discussed. V.L.

**A90-24077**

**AN EXPERIMENTAL STUDY OF SEPARATED FLOW PAST A LOW-ASPECT-RATIO DELTA WING [EKSPERIMENTAL'NOE ISSLEDOVANIE OTRYVNOGO OBTEKANIYA TREUGOL'NOGO KRYLA MALOGO UDLINENIIA]**

S. B. ZAKHAROV and A. V. ZUBTSOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 8-12. In Russian. refs

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An experimental study was made of subsonic separated flow of a gas past a low-aspect-ratio delta wing, with a triangular dividing plate mounted in the plane of symmetry of the lee side of the wing. For a zero slip angle, the critical angle of attack corresponding to the transition to nonsymmetric flow is related to the height of the dividing plate. Flow visualization and measurements of the aerodynamic wing characteristics have made it possible to identify four different regimes of separated flow within the angle of attack range 0-90 deg. V.L.

**A90-24078**

**AERODYNAMIC INTERFERENCE OF PRISMATIC ENGINE NACELLES WITH THE WING AT SUPERSONIC VELOCITIES [AERODINAMICHESKAIA INTERFERENTSIYA PRIZMATICHESKIKH MOTOGONDOL S KRYLOM PRI SVERKHZVUKOVYKH SKOROSTIYAKH]**

M. D. BRODETSKII, A. A. RAFAELIANTS, A. M. KHARITONOV, and G. A. CHEREMUKHIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 13-21. In Russian. refs

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Results of an experimental study of the effect of engine nacelles on the integral and distributed aerodynamic characteristics of a model of a supersonic passenger aircraft at M 2.27 are examined. A method is proposed for reducing the induced-wave wing drag through the correction of wing profiles in the negative interference region. The efficiency of the correction procedure is illustrated by a specific example. V.L.

**A90-24079**

**CALCULATION OF NONSEPARATED TRANSONIC FLOW PAST SWEEP WINGS WITH ALLOWANCE FOR VISCOSITY [RASCHET BEZOTRYVNOGO OKOLOZVUKOVOGO OBTEKANIYA STRELOVIDNYKH KRYL'EV S UCHETOM VLIANIYA VIAZKOSTI]**

N. A. VLADIMIROVA, V. V. VYSHINSKII, and G. A. SHCHEKIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 22-30. In Russian. refs

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The problem of calculating three-dimensional transonic nonseparated flow past isolated swept wings with allowance for viscosity is solved using an iteration scheme in the boundary layer approximation. The external potential flow is calculated using a finite difference method based on the numerical solution of full equations for the velocity potential. Flow in the compressed three-dimensional boundary layer in the laminar, transition, and turbulent flow regions is calculated using a differential method permitting the existence of both a fixed and a natural transition. V.L.

**A90-24080**

**EFFECT OF TANGENTIAL INJECTION ON FLOW IN A LAMINAR BOUNDARY LAYER [O VLIANII TANGENTSIAL'NOGO VDUVA NA TECHENIE V LAMINARNOM POGRANICHNOM SLOE]**

V. V. BOGOLEPOV and I. I. LIPATOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 31-38. In Russian. refs

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The interaction between a tangential wall jet and counterflow in a laminar boundary layer is investigated analytically. It is shown that, for a small step height and a low flow rate of the injected gas, flow past the step is described by a system of Navier-Stokes equations. Numerical solutions of this system of equations are obtained for several values of the parameters characterizing the step height and the injected gas flow rate. The flow structure is analyzed for parameter values corresponding to changes in surface friction upstream of the step caused by the induced interaction. V.L.

**A90-24081**

**EFFECT OF SURFACE RIBBLETS ON THE VELOCITY PROFILE OF AN INCOMPRESSIBLE BOUNDARY LAYER [VLIANIE MALOGO OREBRENIIA POVERKHNOSTI NA PROFIL' SKOROSTI NESZHIMAEMOGO POGRANICHNOGO SLOIA]**

V. V. MIKHAILOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 39-44. In Russian.

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The effect of surface riblets on the velocity profile of flow of an incompressible two-dimensional boundary layer is investigated analytically using higher asymptotic approximations. It is noted that this approach is particularly useful in the analysis of boundary layer stability problems. The solutions obtained here can also be applied to a turbulent boundary layer in the case where the riblet pitch is much smaller than the thickness of the laminar boundary sublayer. V.L.

**A90-24082**

**AN EXPERIMENTAL STUDY OF THE EFFECT OF THE REYNOLDS NUMBER ON FLOW PAST A SWEEP WING AT TRANSONIC VELOCITIES [EKSPERIMENTAL'NOE ISSLEDOVANIE VLIANIYA CHISLA REINOL'DSA NA OBTEKANIE STRELOVIDNOGO KRYLA PRI OKOLOZVUKOVYKH SKOROSTIYAKH]**

V. M. GADETSKII TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 45-51. In Russian.

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Results of an experimental study of the effect of the Reynolds number on transonic flow past a 35-degree swept wing are reported. It is shown that the Re number depends strongly on the pressure drop over the cross sections of the cantilever part of the wing at

angles of attack corresponding to the onset of nonlinear changes in aerodynamic characteristics. The effect of the Re number is particularly strong in the central part of the wing cantilever. V.L.

#### A90-24086

### MODEL PROBLEMS OF CONTINUOUS CONTROL LAW OPTIMIZATION FOR A TENSOMETRIC AERODYNAMIC EXPERIMENT [MODEL'NYE ZADACHI OPTIMIZATSII NEPRERYVNYKH ZAKONOV UPRAVLENIIA TENZOMETRICHESKIM AERODINAMICHESKIM EKSPERIMENTOM]

V. I. POMINOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 78-86. In Russian.

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The problem of continuous control law optimization for a tensometric aerodynamic experiment is investigated with reference to model examples, with particular attention given to the effect of such factors as the type of the regression equations, real properties of the actuating mechanism of the control system, statistical properties of measurement results, and the type of the optimality criterion used. Optimal control laws are compared with the linear control law case. V.L.

#### A90-24088

### FLOW PAST A WING/FUSELAGE COMBINATION WITH SEPARATION FROM THE SIDE EDGES OF THE WING [OBTEKANIE KOMBINATSII KRYLO-KORPUS S OTRYVOM POTOKA OT BOKOVYKH KROMOK KRYLA]

A. V. VOEVODIN and G. G. SUDAKOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 98-101. In Russian. refs

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A family of self-similar solutions is obtained for the plane problem of separated flow past the side edge of a wing. The solutions are then used to calculate flow past three-dimensional wing/fuselage configurations in the region where the leading and side edges meet. The calculation algorithm and results are presented. V.L.

#### A90-24089

### PSEUDOSHOCK AND SEPARATED FLOW IN RECTANGULAR DUCTS [PSEVDOSKACHOK I OTRYVNOE TECHENIE V PRIAMOUGOL'NYKH KANALAKH]

V. I. PENZIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 105-112. In Russian. refs

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Supersonic decelerating flows in straight ducts of rectangular cross section with a side ratio of 1-7 were investigated experimentally in the Mach range 2.2-4.2. It is shown that, depending on the Mach number and the side ratio, the deceleration of the supersonic flow to sonic velocities may occur either in the pseudoshock, extending 10-15 duct dimensions, or in nonsymmetric separated flow with a length of 20-30 duct dimensions. V.L.

#### A90-24094

### ASYMPTOTIC SOLUTION OF THE OPTIMAL-DEFLECTION PROBLEM FOR A WING LEADING EDGE AT SUBSONIC FLOW VELOCITIES [ASIMPTOTICHESKOE RESHENIE ZADACHI OB OPTIMAL'NOM OTKLONENII NOSKA KRYLA PRI DOZVUKOVYKH SKOROSTIAKH POTOKA]

I. M. PANTELEEV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 9-18. In Russian.

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The optimal deflection characteristics for a sharp wing leading edge are determined using the method of matched asymptotic expansions under low angle of attack conditions. Sufficiently simple expressions are obtained for optimal deflection angles as well as for the reduction in drag for a given angle of attack. Calculations are presented for wings of triangular planform, and the asymptotic solution is compared with a numerical one obtained by the panel method. B.J.

#### A90-24095

### DESIGN OF SYMMETRIC PROFILES WITH MAXIMUM CRITICAL FLOW MACH NUMBER UNDER PRESCRIBED CONSTRAINTS [PROEKTIROVANIE SIMMETRICHNYKH PROFILEI S MAKSIMAL'NYM KRITICHESKIM CHISLOM MAKHA POTOKA PRI ZADANNYKH OGRANICHENIIAKH]

S. M. AUL'CHENKO, A. F. LATYPOV, and V. G. SAMARIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 19-28. In Russian. refs

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The problem of designing a symmetric profile providing for shock-free flow with a maximum Mach number is considered. The approach used is a design-optimization method based on the simultaneous solution of the optimization problem and the flow problem using the Euler equations. B.J.

#### A90-24096

### EIGENVALUE PROBLEM IN THE THEORY OF FLOW PAST THIN PROFILES AT HIGH SUPERSONIC VELOCITY [ZADACHA NA SOBSTVENNYE ZNACHENIIA V TEORII OBTEKANIIA TONKIKH PROFILEI S BOL'SHOI SVERKHZVUKOVOI SKOROST'IU]

S. V. MANUILOVICH TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 29-38. In Russian. refs

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Attention is given to the plane-parallel supersonic flow of an ideal gas past a thin profile whose shape at large distances from the leading edge is described by a power function of the longitudinal coordinate. An analysis is made of the downstream propagation of perturbations introduced by singularities of the shape of the front part of the profile. The search for these perturbations is carried out on the basis of an inverse-problem formulation. B.J.

#### A90-24099

### EFFECT OF THE DESIGN OF A DIFFUSER WITH TANGENTIAL INJECTION ON THE STARTING AND SEPARATION RATIOS OF PRESSURES [VLIANIE KONSTRUKTSII DIFFUZORA S TANGENTSIAL'NYM VDUVOM NA PUSKOVYE I SRYVNYE OTNOSHENIIA DAVLENII]

I. V. BABCHENKO and N. A. SHUSHIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 57-64. In Russian.

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An analysis is made of the starting and separation ratios of pressures in a two-dimensional wind tunnel with tangential supersonic injection into the diffuser. The wedge-shaped injection nozzles used make it possible to obtain smaller pressure ratios than in the case of nozzles that form a step along the flow. B.J.

#### A90-24103

### APPLICATION OF FEDORENKO'S MULTIGRID METHOD FOR CALCULATING TRANSONIC FLOW PAST A PROFILE [PRIMENENIE MNOGOSETOCHNOGO METODA FEDORENKO DLIA RASCHETA TRANSZVUKOVOGO OBTEKANIIA PROFILIA]

A. P. ARALOV and A. A. SHAGAEV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 93-97. In Russian. refs

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A Fedorenko multigrid method using the Bubnov-Galerkin projection-grid scheme is developed for solving the problem of potential transonic flow past a profile. Calculation results are presented which demonstrate an increase in the convergence speed of the multigrid algorithm when a specified procedure for constructing the projection-grid scheme on auxiliary grids is used. B.J.

#### A90-24105

### A NEW QUICK METHOD FOR INTEGRATING EULER EQUATIONS FOR PLANE TRANSONIC FLOWS [NOVYI BYSTRYI METOD INTEGRIROVANIA URAVNENII EILERA DLIA PLOSKIKH TRANSZVUKOVYKH TECHENII]

V. M. NEILAND TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol.

## 02 AERODYNAMICS

19, no. 3, 1988, p. 9-17. In Russian. refs

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A new numerical method is proposed for calculating transonic flow of an ideal gas past plane bodies. The use of some fundamental properties of the flow for free-stream Mach approaching 1, along with exact solutions, has made it possible to increase the speed of the method by about two orders of magnitude in comparison with the existing methods for integrating Euler equations. Examples of flow past a profile are presented, and the results are compared with experimental results and data in the literature. V.L.

### A90-24107

#### **CALCULATION OF TRANSONIC AXISYMMETRIC FLOW PAST AN ENGINE NACELLE WITH ALLOWANCE FOR VISCOSITY [RASHCHET OKOLOZVUKOVOGO OSESIMMETRICHNOGO OBTEKANIIA MOTOGONDOLY S UCHETOM VIAZKOSTI]**

V. V. VYSHINSKII and S. V. LIAPUNOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 26-33. In Russian. refs

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A method is for calculating transonic axisymmetric flow past an engine nacelle with allowance for viscosity is proposed which uses a full potential equation as the equation of motion. The problem is solved in the meridional plane by the finite difference method using a relaxation algorithm. Viscosity is considered in the boundary layer approximation. Laminar and turbulent boundary layers are calculated using the differential method. Examples of calculations are presented. V.L.

### A90-24109

#### **CALCULATION OF FLOWS OF AN IDEAL GAS IN NOZZLES AND JETS BY THE RELAXATION METHOD [RASHCHET TECHENII IDEAL'NOGO GAZA V SOPLAKH I STRUIAKH RELAKSATSIONNYM METODOM]**

A. N. LANIUK and L. S. MILESHIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 46-51. In Russian. refs

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The principles of the relaxation method for solving two-dimensional stationary Euler equations are examined with particular reference to the direct and inverse problems in Laval nozzle theory. Solutions to several problems obtained by the method proposed here are presented, and the results are compared with experimental and analytical data in the literature. V.L.

### A90-24110

#### **EFFECT OF THE CROSS-SECTIONAL SHAPE OF A STRAIGHT DUCT ON SUPERSONIC FLOW STAGNATION [VLIIANIE FORMY POPERECHNOGO SECHENIIA PRIAMOGO KANALA NA TORMOZHENIE SVERKHZVUKOVOGO POTOKA]**

V. I. PENZIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 52-59. In Russian. refs

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Supersonic stagnation flows in straight ducts with cross sections in the form of a ring, a circular sector, and a segment were investigated experimentally in the Mach number range 3.2-4.2. It is shown that, in contrast to rectangular ducts with a height-to-width ratio greater than 3, practically separation-free flows of the pseudoshock type may form in annular and sector-shaped ducts. An increase in boundary layer thickness during the downstream motion of the pressure recovery region in a sector duct may lead to the transition of the pseudoshock to a nonsymmetrical separated flow. V.L.

### A90-24113

#### **NONSTATIONARY LIQUID FLOW OF A FLUID IN THE CORE OF A CONICAL VORTEX SHEET [NESTATSIONARNOE TECHENIE ZHIDKOSTI V IADRE KONICHESKOI VIKHREVOI PELENY]**

A. M. GAIFULLIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 87-90. In Russian. refs

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The effect of nonstationary changes in flow characteristics on the structure of the core of a vortex sheet shed from the wing edges is examined using a simple ideal fluid model. Although axisymmetric vortex breakdown is a nearly stationary phenomenon, it is suggested that nonlinear nonstationary effects may play an important role in the mechanism of vortex formation and its evolution. The behavior of the core of a conical vortex flow in the case of nonstationary changes in incoming flow velocity is considered as an example. V.L.

### A90-24114

#### **A METHOD FOR THE ACTIVE CONTROL OF THE BOUNDARY LAYER CONDITION [METOD AKTIVNOGO KONTROLIA SOSTOIANIIA POGRANICHNOGO SLOIA]**

L. M. MOSKALIK, A. A. PILIPENKO, I. E. FROLOVA, and G. K. SHAPOVALOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 91-95. In Russian. refs

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The objective of the experimental study reported here was to investigate the possibility of boundary layer laminarization through Tollmien-Schlichting wave cancellation. In the experiments, the amplitude of Tollmien-Schlichting waves was reduced by a factor of 2.5-3 by using an electronic phase delay block in the boundary layer. The Tollmien-Schlichting wave cancellation effect was observed for a length equal to 20 percent of the wing chord. The perturbation structure of the longitudinal velocity component in the boundary layer is examined. V.L.

### A90-24115

#### **DYNAMIC CHARACTERISTICS OF ONE-DIMENSIONAL GAS FLOW WITH FRICTION [DINAMICHESKIE KHAARAKTERISTIKI ODNOMERNOGO TECHENIIA GAZA S TRENIEM]**

I. L. PIS'MENNYI TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 96-103. In Russian. refs

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Transfer functions and frequency characteristics are obtained for one-dimensional subsonic flow of a gas, with and without friction, in a pipe of constant cross section. In the analysis, the flow is treated as a linearized system with distributed parameters. The characteristics determined here can be used for studying oscillatory processes in the gas flow path of a gas turbine powerplant, particularly surge phenomena and rotational stall. V.L.

### A90-24120

#### **CALCULATION OF THE FRONT OR REAR PART OF A FLAT BODY IN SUBSONIC FLOW WITH THE EXTREMUM VALUE OF THE CRITICAL MACH NUMBER [RASHCHET GOLOVNOI ILI KORMOVOI CHASTI PLOSKOGO TELA, OBTEKAEMOGO DOZVUKOVYM POTOKOM S MAKSIMAL'NO VOZMOZHNYM KRITICHESKIM CHISLOM MAKHA]**

S. A. SHCHERBAKOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 10-18. In Russian.

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A method is developed for the dimensional profiling of the front or rear part of a flat body situated in a flow with the extremum value of the critical Mach number. The solution is obtained using the Green function of the elliptical boundary value problem for the Chaplygin equation in velocity hodograph variables. Calculation results are presented for the critical Mach number range from 0.3 to 0.9. B.J.

### A90-24122

#### **MULTILEVEL METHOD FOR CALCULATING AERODYNAMIC LOADS ON A FLIGHT VEHICLE [MNOGOUROVNEVYI METOD RASHCHETA AERODINAMICHESKIKH NAGRUZOK NA LETATEL'NOM APPARATE]**

V. D. IL'ICHEV and V. V. MOZZHILKIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 26-36. In Russian. refs

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The paper proposes a method for calculating aerodynamic loads that is multilevel in terms of the geometric detail of the flight vehicle. The method is based on panel methods and Fedorenko's



imbedded grid method. Calculations of the aerodynamic characteristics of coplanar plates of infinite span harmonically oscillating in an incompressible fluid flow are carried out by way of illustration, showing the sufficiently high accuracy and the effectiveness of the proposed approach. B.J.

#### A90-24123

##### THE EFFECT OF LONGITUDINAL FINS ON TURBULENT FRICTION DRAG [VLIANIE PRODOL'NOGO OREBRENIIA NA SOPROTVLENIE TURBULENTNOGO TRENIIA]

G. V. ENIUTIN, I. A. LASHKOV, N. V. SAMOILOVA, I. V. FADEEV, and E. A. SHUMILKINA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 37-44. In Russian. refs  
Copyright

The effect of longitudinal fins on the turbulent friction drag on a flat plate was investigated in a low-turbulence wind tunnel. Eight different types of surfaces with small fins were investigated which differ in terms of fin shape and dimensions. It is shown that a range of parameters exists for each of these surfaces in which the turbulent friction drag is less than for a smooth plate. Here, the maximum reduction of the drag coefficient due to the fins depending on the fin geometry amounted to 4 to 8 percent. B.J.

#### A90-24124

##### INVESTIGATION OF THE FLOW STRUCTURE BEHIND THE ROTATING BLADES IN THE ELBOW OF A WIND TUNNEL IN THE CASE OF ACOUSTIC EXCITATION [ISSEDOVANIE STRUKTURY TECHENIIA ZA LOPATKAMI POVOROTNOGO KOLENA AERODINAMICHESKOI TRUBY PRI AKUSTICHESKOM VOZDEISTVII]

S. P. BARDAKHANOV, V. V. KOZLOV, and I. P. NOSYREV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 45-51. In Russian. refs  
Copyright

Measurements performed in a low-turbulence subsonic wind tunnel show that an elbow with a cascade of rotating blades constitutes a powerful generator of vortex disturbances in a wide frequency range. In the turbulent wake of the rotating blades, acoustic oscillations are transformed into vortex disturbances or coherent structures, which are an additional source of flow disturbances. B.J.

#### A90-24131

##### AN INVESTIGATION OF FILLETS IN WING-FUSELAGE JOINTS AT SUBSONIC VELOCITIES [ISSEDOVANIE ZALIZOV V SOPRIAZHENII KRYLA S FIUZELIAZHEM PRI DOZVUKOVYKH SKOROSTIAXH]

V. A. BARINOV, I. L. INESHIN, and G. A. IUDIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 111-115. In Russian.  
Copyright

The paper presents results of calculations and experiments concerning the effect of fillets in wing-fuselage joints. Specifically, the effects of fillets on the aerodynamic characteristics were investigated for a passenger-aircraft model. It is shown that the use of a smooth contours in the regions where the front and back parts of the wing are joined with the fuselage leads to improved flow around the body and a better lift-drag ratio. B.J.

#### A90-24136

##### THE LOCAL SURFACE VARIATION METHOD IN PROFILE SHAPE OPTIMIZATION PROBLEMS [METOD LOKAL'NYKH VARIATSII POVERKHNOSTI V ZADACHAKH OPTIMIZATSII FORMY PROFILIA]

N. P. BUZOVERIA and D. P. KROTKOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 1-12. In Russian. refs  
Copyright

A method for constructing local profile variations is described, and its application to the solution of problems of profile shape optimization in subsonic flow of an ideal gas is discussed. Results are presented for the problems of wave drag minimization, construction of a profile contour for a given pressure distribution,

and profile nose optimization. Some profile shapes are analyzed with allowance for viscosity in the context of a boundary layer model. V.L.

#### A90-24138

##### CALCULATION OF SUPERSONIC FLOW PAST A WING/FUSELAGE COMBINATION WITH THE RESOLUTION OF A COMPRESSION SHOCK FROM THE WING [RASCHET SVERKHZVUKOVOGO OBTAKANIIA KOMBINATSII KRYLA I FIUZELIAZHA S VYDELENIEM SKACHKA UPLOTNENIIA OT KRYLA]

S. M. BOSNIAKOV, E. V. KARPOV, and S. V. MIKHAILOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 24-32. In Russian. refs  
Copyright

An approach to the calculation of the flow field and flow parameter distribution on the surface of a wing and a fuselage has been developed and implemented in software written in FORTRAN-IV. The approach involves subdivision of the calculation region into subregions, construction of a computation grid for each subregion, and solution of the full Euler system by the Godunov method. Compression shocks from the wing and the fuselage are resolved in explicit form. V.L.

#### A90-24139

##### A METHOD FOR CALCULATING THE LOCATION AND INTENSITY OF A CONICAL HEAD SHOCK ON THE LOWER SURFACE OF A DELTA WING WITH SUPERSONIC EDGES [METOD RASCHETA POLOZHENIIA I INTENSIVNOSTI KONICHESKOGO GOLOVNOGO SKACHKA UPLOTNENIIA NA NIZHNEI POVERKHNOSTI KRYLA TREUGOL'NOI FORMY V PLANE SO SVERKHZVUKOVYMI KROMKAMI]

T. M. PRITULO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 33-40. In Russian. refs  
Copyright

A method developed in a previous study (Pritulo, 1983) for calculating flow past wings with straight supersonic leading and supersonic trailing edges is used here to determine the location and intensity of a conical head shock developing on the lower surface of a delta wing. The problem is solved using an isentropic formulation; the shock magnitude is comparable with the angle of attack. The results obtained are found to be in good agreement with numerical calculations. V.L.

#### A90-24140

##### AERODYNAMIC CHARACTERISTICS OF THIN BODIES MOVING IN A GAS WITH SHOCK WAVES [AERODINAMICHESKIE KHARAKTERISTIKI TONKIKH TEL, DVIZHUSHCHIKHSIA V GAZE S UDARNYMI VOLNAMI]

V. N. GOLUBKIN and V. V. NEGODA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 41-49. In Russian. refs  
Copyright

Flow past a thin axisymmetric body moving at a supersonic velocity is analyzed in the case where a weak shock wave is incident on the body. To calculate nonstationary aerodynamic characteristics in the context of linearized theory, a method is developed which is based on an analogy with the problem of entry into an equivalent vertical gust. Sufficiently simple formulas are obtained and parametric calculations performed which show that nonstationary loads generally have maxima that significantly exceed their initial values and cannot be obtained in the quasi-stationary approximation. V.L.

#### A90-24142

##### SEPARATION DEVELOPMENT AND ITS EFFECT ON THE AERODYNAMICS OF SUPERCRITICAL PROFILES AT TRANSONIC VELOCITIES [RAZVITIE OTRYVA I EGO VLIANIE NA AERODINAMIKU SVERKHKRITICHESKIKH PROFILEI PRI OKOLOZVUKOVYKH SKOROSTIAXH]

V. D. BOKSER TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 60-69. In Russian. refs  
Copyright



## 02 AERODYNAMICS

The development of turbulent boundary layer separation in the diffuser section of supercritical profiles is investigated for the case of transonic flow (Mach 0.50-0.85) based on an analysis of experimental pressure distribution and local supersonic zone. Approximate experimental methods are proposed for determining three characteristic types of separation, and the effect of the Mach number and lifting force coefficient on the separation is discussed. The factors responsible for a reduction of the lifting properties and an increase in total drag in the case of transonic flow past supercritical profiles of relative thickness 9, 12, and 15 percent are discussed. V.L.

**A90-24143**  
**INTERACTION BETWEEN A VIBRATING COMPRESSION SHOCK AND A BOUNDARY LAYER [VZAIMODEISTVIE VIBRIUIUSHCHEGO SKACHKA UPLOTNENIIA S POGRANICHNYM SLOEM]**

S. N. TIMOSHIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 70-79. In Russian. refs  
Copyright

The problem of interaction between a vibrating compression shock and a laminar boundary layer is analyzed in the context of asymptotic theory of viscous gas flow for high Reynolds numbers. The vibration amplitude and frequency as well as shock intensity are selected in such a way as to obtain a flow described by nonlinear nonstationary boundary layer equations in the viscous sublayer of the interaction region. It is shown that, in the case of high-frequency vibrations, the shock is stationary but smoothed, with the shock pressure increasing continuously. Interaction flow in the presence of a smoothed shock is investigated in the linear approximation. V.L.

**A90-24144**  
**A STUDY OF THE LAMINAR-TURBULENT BOUNDARY LAYER TRANSITION ON THE WINDWARD SIDE OF A DELTA WING WITH A CONICAL SURFACE [ISSLEDOVANIE PEREKHODA LAMINARNOGO POGRANICHNOGO SLOIA V TURBULENTNYI NA NAVETRENNOI STORONE TREUGOL'NOGO KRYLA S KONICHESKOI POVERKHNOST'IU]**

I. A. KONDRAT'EV, A. P. KOSYKH, and A. IA. IUSHIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 80-88. In Russian. refs  
Copyright

Experimental data are presented on the Reynolds numbers of the turbulent transition on the lower surface of a wing formed by a circular cone surface. The sweep angle of the sharp leading edges of the wing was 70 deg; the Mach number was 5; the angle of attack was varied in the range 2-19.33 deg. The effect of transverse spread characteristics on the transition in the plane of symmetry is examined. V.L.

**A90-24149**  
**CONSTRUCTION OF A WING SURFACE IN A NONVISCOUS TRANSONIC FLOW FROM A GIVEN PRESSURE DISTRIBUTION [POSTROENIE POVERKHNOSTI KRYLA V NEVIAZKOM OKOLOZVUKOVOM POTOKE PO ZADANNOMU RASPREDELENIU DAVLENIIA]**

A. E. OSOVSKII and V. I. SAVITSKII TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 130-136. In Russian. refs  
Copyright

The paper is concerned with the problem of constructing the surface shape of a finite-span wing characterized by a given pressure distribution and a given distribution of the trailing edge thickness, with allowance made for the effect of the fuselage. A numerical algorithm is developed for solving this problem in the context of transonic theory of small perturbations. Examples of calculations are presented. V.L.

**A90-24150**

**EFFECT OF SIMILARITY PARAMETERS ON THE AERODYNAMIC QUALITY AND MOMENT CHARACTERISTICS OF A SUPERSONIC WING WITH BLUNT EDGES [VLIANIE PARAMETROV PODOBIIA NA AERODINAMICHESKOE KACHESTVO I MOMENTNYE KHARAKTERISTIKI SVERKHZVUKOVOGO KRYLA S ZATUPLENNymi KROMKAMI]**

V. S. NIKOLAEV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 137-141. In Russian.  
Copyright

Analytical expressions for the aerodynamic characteristics of a thin trapezoidal wing with a flat lower surface and blunt cylindrical leading edges are obtained for the case of weak viscous supersonic interaction. Consideration is given to the cases on a lee and a windward upper surface consisting of two halves. Formulas are presented for estimating the effect of finite Mach and Reynolds numbers on the maximum aerodynamic quality and balancing angle of attack. V.L.

**A90-24154**

**JET FLAP THEORY [K TEORII STRUINOGO ZAKRYLKA]**

M. A. BRUTIAN, P. L. KRAPIVSKII, and S. V. KUZ'MIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 1-7. In Russian. refs  
Copyright

A jet flap model is proposed which allows for the ejection properties of the jet in addition to its lifting properties, taken into account in Spence's (1956) theory. The ejection properties of the jet are considered in terms of sink distribution along the jet axis; the sink distribution law is taken from the Goertler solution for turbulent jets. An integrodifferential equation for the jet shape is obtained in the context of linear theory. Results of numerical calculations of the jet shape and aerodynamic coefficients are presented. V.L.

**A90-24155**

**WING-FUSELAGE INTERFERENCE REGIMES AT SUPERSONIC FLIGHT VELOCITIES [REZHIMY INTERFERENTSI KRYLA I KORPUSA PRI SVERKHZVUKOVYKH SKOROSTIAXH POLETA]**

IU. I. LOBANOVSKII TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 8-16. In Russian. refs  
Copyright

The paper is concerned with the effect of changes in the geometry and parameters of supersonic incoming flow on the polars of wing configurations representing a combination of a fuselage with a low-aspect-ratio wing. The existence of two regimes of wing-fuselage interference at high supersonic flight velocities, observed in polar asymmetry, is demonstrated. The boundary between these regimes is determined for the configurations considered. V.L.

**A90-24156**

**IDEAL PROPELLER IN COMPRESSIBLE GAS FLOW IN A WIND TUNNEL [IDEAL'NYI PROPELLER V POTOKE SZHIMAEMOGO GAZA V AERODINAMICHESKOI TRUBE]**

V. V. KELDYSH TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 17-27. In Russian.  
Copyright

A study is made of the effect of a wind tunnel with a closed test section on the efficiency of a propeller and on the propeller-generated flow. The treatment is confined to the classical scheme of an ideal propeller, assuming that all of the propeller power input is transformed to the ambient kinetic energy. In a compressible medium, this implies an adiabatic flow over the entire perturbed flow space. It is shown that the distance from the propeller at which asymptotic flow parameters are in a closed wind tunnel is not larger than in open space. V.L.

A90-24157

**USING THIRD-FOURTH ORDER COMPACT SCHEMES FOR CALCULATING GAS FLOWS IN NOZZLES WITH HIGH SUPERSONIC M NUMBERS ON THE BASIS OF SIMPLIFIED NAVIER-STOKES EQUATIONS [PRIMENENIE KOMPAKATNYKH SKHEM TRE'T'EGO-CHEVERTOGO PORIADKA DLIA RASCHETA TECHENIIA GAZA V SOPLAKH S BOL'SHIMI SVERKHZVUKOVYMI CHISLAMI M NA OSNOVE UPROSHCHENNYKH URAVNENII NAV'E-STOKSA]**

A. P. BYRKIN, T. A. TIMOFEEVA, and A. I. TOLSTYKH TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 28-39. In Russian. refs

Copyright

A numerical algorithm for solving simplified Navier-Stokes equations for a compressible gas has been implemented which employs compact schemes of third-fourth orders of approximation. The algorithm has been used for the numerical modeling of viscous gas flow in wind tunnel nozzles. The calculations based on the algorithm are in satisfactory agreement with experimental results.

V.L.

A90-24158

**CALCULATION OF FLOW PAST FLIGHT VEHICLES OF COMPLEX CONFIGURATIONS AT HIGH SUPERSONIC MACH NUMBERS USING THE HYPERSONIC THEORY OF SMALL PERTURBATIONS [RASCHET OBTOKANIYA LETATEL'NYKH APPARATOV SLOZHNYKH FORM PRI BOL'SHIKH SVERKHZVUKOVYKH CHISLAKH MAKHA S ISPOL'ZOVANIEM GIPERZVUKOVOI TEORII MALYKH VOZMUSHCHENII]**

N. V. VOEVODENKO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 40-46. In Russian. refs

Copyright

A method is described for the numerical solution of problems concerning supersonic and hypersonic flow past bodies of complex configurations. The equations of motion of an ideal gas are integrated using an approach based on the hypersonic theory of small perturbations and the Godunov numerical method. Calculations for a model of an american hypersonic transport aircraft are presented and compared with experimental data.

V.L.

A90-24165

**OPTIMAL NOSE SHAPES OF BODIES OF REVOLUTION IN TRANSONIC FLOW [OPTIMAL'NYE FORMY NOSOVYKH CHASTEI TEL VRASHCHENIIA V TRANSZVUKOVOM POTOKE]**

V. V. VYSHINSKII, E. N. KUZNETSOV, and P. D. MIKHAILOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 103-105. In Russian. refs

Copyright

Results of an experimental study of the nose sections of parabolic bodies of revolution in transonic flow (Mach 0.8-1.2; Re (2.9-3.5) x 10 to the 6th) are reported. The regions of Mach number where a particular nose shape has the lowest drag are determined. Good agreement is obtained between analytical results and the results of the present experiment.

V.L.

A90-24166

**DETERMINATION OF PRESSURE AND HEAT FLOW ON THE FRONT SURFACE OF SMOOTH BLUNT BODIES**

**[OPREDELENIE DAVLENIIA I TEПЛОВОГО ПОТОКА НА ЛОБОВОI ПОВЕРХНОСТИ ГЛАДКИХ ЗАТУПЛЕННЫХ ТЕЛ]**

IU. P. GOLOVACHEV and E. V. TIMOFEEV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 106-109. In Russian. refs

Copyright

Pressure and heat flux distributions on the front surface of smooth blunt bodies are presented for the case of axisymmetric flow in a form that is independent of the Mach number. In conjunction with the known formulas for the pressure and heat flow at the front critical point, the relations proposed here provide values of the above parameters over the entire front surface of

the body over a wide range of conditions, including low supersonic and transonic flow velocities.

V.L.

A90-24167

**EFFECT OF A RECESS ON THE AERODYNAMIC CHARACTERISTICS OF VERY BLUNT BODIES AT SUPERSONIC VELOCITIES [VLIANIE VYEMKI NA AERODINAMICHESKIE KHKARAKTERISTIKI SIL'NO ZATUPLENNYKH TEL PRI SVERKHZVUKOVOI SKOROSTI]**

I. I. AMARANTOVA, V. G. BUKOVSHIN, and V. I. SHUSTOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 110-113. In Russian. refs

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The effect of a recess in the front section of blunt bodies on their aerodynamic characteristics at angles of attack of 0-14 deg was investigated experimentally in supersonic flow at Mach 4 and Re 1.3 x 10 to the 6th. It is found that the shape of the recess has a noticeable effect on all aerodynamic characteristics. This effect is observed over the entire range of angles of attack.

V.L.

A90-24233

**SUPERSONIC FLIGHT VEHICLES [SVERKHZVUKOVYE LETATEL'NYE APPARATY]**

ALEKSANDR I. SHVETS Moscow, Izdatel'stvo Moskovskogo Universiteta, 1989, 240 p. In Russian. refs

Copyright

Results of theoretical and experimental studies of supersonic waveriders are reviewed. In particular, attention is given to the principal methods for calculating flow past caret wings, interference configurations of maximum aerodynamic quality, physical flow schemes, and results of wind tunnel, ballistic, shock tube, and free flight studies. Some of the important published data relating to the gasdynamic design of supersonic aerodynamic configurations based on compression shock systems are presented in a systematic manner.

V.L.

A90-24342

**REDUCTIONS IN INDUCED DRAG BY THE USE OF AFT SWEEP WING TIPS**

C. W. BURKETT (Southampton, University, England) Aeronautical Journal (ISSN 0001-9240), vol. 93, Dec. 1989, p. 400-405. refs

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Recent experimental and computational studies have indicated that rearward curvature of a wing can reduce the induced drag factor to values less than that obtained from the unswept elliptical wing considered optimal in classical wing theory. Wake non-planarity associated with a wing with aft swept tips has been suggested as a reason for this behavior. This paper provides a systematic examination of the wake non-planarities induced by a variety of wing planforms and quantifies the induced drag reductions which may be expected. Results suggest a dependence of induced drag factor upon angle of attack, and therefore upon lift coefficient. The crescent wing is identified as the planform to derive the most benefit from its non-planar wake shape, typically a 4 percent reduction in induced drag factor at moderate angle of attack.

Author

A90-24354

**UNSTEADY TRANSONIC FLOW AROUND DOUBLE-WEDGE PROFILES**

TH. FRANKE (Aachen, Rheinisch-Westfaelische Technische Hochschule, Federal Republic of Germany) Experiments in Fluids (ISSN 0723-4864), vol. 8, no. 3-4, Dec. 1989, p. 192-198. Research sponsored by DFG. refs

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A double-wedge with a relative thickness d/c greater than 0.15 forms a vortex street in its wake. This was investigated experimentally in the Mach number range of 0.4 to 0.75. The strength and the frequency of the pressure fluctuations which are produced by the vortices, were measured on the surface of the wedge for different chord length and relative thickness, both in chord- and spanwise direction. The density fluctuations around the profile and in the wake were measured with a Mach-Zehnder

interferometer and a schlieren system. Attention was focused on the question concerning to what extent unsteady flows are affected by wall interferences. Author

**A90-24741**

**NONSTATIONARY MOTION OF AN ELASTIC PROFILE IN SUBSONIC INCOMPRESSIBLE FLOW [NEUSTANOVIVSHEESIA DVIZHENIE UPRUGOGO PROFILIA V DOZVUKOVOM NESZHIMAEMOM POTOKE]**

B. A. ERSHOV, I. U. A. MOCHALOVA, and E. V. POLIAKOVA  
Leningradskii Universitet, Vestnik, Matematika, Mekhanika, Astronomiia (ISSN 0024-0850), Oct. 1989, p. 44-50. In Russian. Copyright

A method for studying the motion of an elastic profile in a flow of an incompressible ideal fluid is presented. By using this method, the problem is reduced to that of solving a system of integro-differential equations. The case of the nonstationary motion of a high-lift wing with an elastic aileron is examined as an example. V.L.

**A90-24752**

**THE SHAPE ASSUMED BY A SOFT CONICAL SHELL IN FLUID FLOW [O FORME, PRINIMAEMOI V POTOKE ZHIKOSTI MIAGKOI KONICHESKOI OBOLOCHKOI]**

A. S. SIKAZAN and V. A. TEMNENKO (Simferopol'skii Gosudarstvennyi Universitet, Simferopol, Ukrainian SSR) Dinamicheskie Sistemy (ISSN 0203-3755), no. 8, 1989, p. 8-13. In Russian. refs Copyright

The problem of the equilibrium of a conically cut parachute canopy in fluid flow is stated with allowance for the presence of designed openings in the canopy. An algorithm for solving the problem is described, and its software implementation is discussed. It is shown that the aerodynamic characteristics of the conical canopy may differ substantially from those of a flat-circle canopy. V.L.

**A90-24753**

**ANALYTICAL SOLUTION OF THE PROBLEM OF NONAXISYMMETRIC POTENTIAL FLOW PAST A SPHERICAL CANOPY - A SUMMARY OF THE PRINCIPAL ASYMPTOTIC FORMULAS AND QUALITATIVE ANALYSIS [ANALITICHESKOE RESHENIE ZADACHI O NEOSESIMMETRICHNOM POTENTIAL'NOM OBEKANII SFERICHESKOGO KUPOLA - SVODKA OSNOVNYKH FORMUL, ASIMPTOTIKI, KACHESTVENNYI ANALIZ]**

V. A. TEMNENKO (Simferopol'skii Gosudarstvennyi Universitet, Simferopol, Ukrainian SSR) Dinamicheskie Sistemy (ISSN 0203-3755), no. 8, 1989, p. 14-22. In Russian. refs Copyright

The principal results of analytical solutions for the problem of potential flow past a spherical parachute canopy at angle of attack are summarized, and expressions are presented for the fluid velocity vector components on the canopy surface for the case of longitudinal and transverse flow. Coordinate, parametric, and asymptotic expansions of the velocity vector components are obtained; the problem of the shape of the surface current lines is solved in quadratures. The applicability limits of the relations obtained here are defined. V.L.

**A90-24825#**

**IN QUEST OF THE LAMINAR-FLOW AIRLINER - FLIGHT EXPERIMENTS ON A T-33 JET TRAINER**

DEZSO GEORGE-FALVY (Boeing Commercial Airplanes, Seattle, WA) Hungarian Aeronautical Science Conference, 9th, Budapest, Hungary, Nov. 10-12, 1988, Paper. 19 p. refs

This paper first gives a brief, general overview of laminar flow control, pointing out its potential benefits, limitations and the current design approaches. Then, it describes a series of laminar flow flight experiments done on a modified T-33A 'Silver Star' jet trainer. Experimental techniques used for diagnosing the state of the boundary layer and determining the location of transition from laminar to turbulent flow are discussed, including boundary layer

pressure sampling probes, hot-film anemometry and flow visualization by sublimation or liquid crystal coatings. A simple, inexpensive, yet highly-reliable data acquisition system used in these experiments is described. Surface quality requirements and measurement techniques are also discussed showing new data on the limits of admissible surface protuberances obtained during the subject tests. Author

**A90-25028\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**UNSTEADY EULER ANALYSIS OF THE FLOWFIELD OF A PROPPAN AT AN ANGLE OF ATTACK**

M. NALLASAMY (NASA, Lewis Research Center; Sverdrup Technology, Inc., Cleveland, OH) and J. F. GROENEWEG (NASA, Lewis Research Center, Cleveland, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 18 p. refs (AIAA PAPER 90-0339) Copyright

The paper examines the effects of angle of attack of a propfan on the blade loading and details of the flowfield by solving the unsteady three-dimensional Euler equations. The configuration considered is the SR7L propeller at cruise condition and the inflow angles considered are 4.6, 1.6 and -0.4 deg. The results indicate that the blade response is nearly sinusoidal at low inflow angles (1.6 and -0.4 deg) and significant deviations from sinusoidal behavior occur at an inflow angle of 4.6 deg due to the presence of strong shocks on both suction and pressure surfaces of the blade. The detailed flow in the blade passages shows that a shock formed on the suction surface during the highly loaded portion of the revolution extends across the passage to the pressure surface. An increase in inflow angle results in an increase in blade loading on the down-going side and a decrease in loading on the up-going side. Author

**A90-25041\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**NUMERICAL SOLUTIONS OF THE LINEARIZED EULER EQUATIONS FOR UNSTEADY VORTICAL FLOWS AROUND LIFTING AIRFOILS**

JAMES R. SCOTT (NASA, Lewis Research Center, Cleveland, OH) and HAFIZ M. ATASSI (Notre Dame, University, IN) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 20 p. refs (AIAA PAPER 90-0694) Copyright

A linearized unsteady aerodynamic analysis is presented for unsteady, subsonic vortical flows around lifting airfoils. The analysis fully accounts for the distortion effects of the nonuniform mean flow on the imposed vortical disturbances. A frequency domain numerical scheme which implements this linearized approach is described, and numerical results are presented for a large variety of flow configurations. The results demonstrate the effects of airfoil thickness, angle of attack, camber, and Mach number on the unsteady lift and moment of airfoils subjected to periodic vortical gusts. The results show that mean flow distortion can have a very strong effect on the airfoil unsteady response, and that the effect depends strongly upon the reduced frequency, Mach number, and gust wave numbers. Author

**A90-25042\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**SWEPT WING ICE ACCRETION MODELING**

M. G. POTAPCZUK and C. S. BIDWELL (NASA, Lewis Research Center, Cleveland, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 25 p. refs (AIAA PAPER 90-0756) Copyright

An effort to develop a three-dimensional ice accretion modeling method is initiated. This first step toward creation of a complete aircraft icing simulation code builds on previously developed methods for calculating three-dimensional flowfields and particle trajectories combined with a two-dimensional ice accretion calculation along coordinate locations corresponding to streamlines. This work is intended as a demonstration of the types of calculations necessary to predict a three-dimensional ice accretion. Results of calculations using the 3D method for a MS-317 swept

wing geometry are projected onto a 2D plane normal to the wing leading edge and compared to 2D results for the same geometry. These results indicate that the flowfield over the surface and the particle trajectories differed for the two calculations. This led to lower collection efficiencies, convective heat transfer coefficients, freezing fractions, and ultimately ice accumulation for the 3D calculation. R.E.P.

**A90-25043\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**ENGINE INLET DISTORTION IN A 9.2 PERCENT SCALED VECTORED THRUST STOVL MODEL IN GROUND EFFECT**

ALBERT L. JOHNS, GEORGE NEINER (NASA, Lewis Research Center, Cleveland, OH), J. D. FLOOD, K. C. AMUEDO, and T. W. STROCK (McDonnell Aircraft Co., Saint Louis, MO) AIAA, ASME, SAE, and American Society for Engineering Education, Joint Propulsion Conference, 25th, Monterey, CA, July 10-12, 1989. 24 p.

(AIAA PAPER 89-2910) Copyright

Advanced Short Takeoff/Vertical Landing (STOVL) aircraft which can operate from remote locations, damaged runways, and small air capable ships are being pursued for deployment around the turn of the century. To achieve this goal, a cooperative program has been defined for testing in the NASA Lewis 9- by 15-foot Low Speed Wind Tunnel (LSWT) to establish a database for hot gas ingestion, one of the technologies critical to STOVL. This paper presents results showing the engine inlet distortions (both temperature and pressure) in a 9.2 percent scale Vectored Thrust STOVL model in ground effects. Results are shown for the forward nozzle splay angles of 0, -6, and 18 deg. The model support system had 4 deg of freedom, heated high pressure air for nozzle flow, and a suction system exhaust for inlet flow. The headwind (freestream) velocity was varied from 8 to 23 kn. Author

**A90-25101**

**THE INFLUENCE OF THE HELICOPTER FUSELAGE ON ITS ROTOR**

MAO SUN (Beijing University of Aeronautics and Astronautics, People's Republic of China) Chinese Journal of Aeronautics (ISSN 1000-9361), vol. 2, Nov. 1989, p. 209-215. refs Copyright

The effect of the helicopter fuselage on its rotor is studied using a simplified free-wake model. Results show that the rotor near-wake is distorted because of the flow field of the fuselage, resulting in large variation on the induced velocity distribution at the rotor plane. It is concluded that the variation of the induced velocity distribution at the rotor plane caused by the fuselage, through distorting the rotor near-wake, is much larger than that induced by the fuselage directly. The calculated results also show that when the size of the fuselage increases, when the distance between the rotor and the fuselage decreases, or when the disc loading increases, the influence of the fuselage on the rotor becomes more important. R.E.P.

**A90-25105**

**A SEMI-ACTUATOR DISK THEORY FOR PREDICTION OF STALL FLUTTER IN AXIAL FLOW COMPRESSORS**

XIAODONG YANG, ZHIMING TANG, and SHENG ZHOU (Beijing University of Aeronautics and Astronautics, People's Republic of China) Chinese Journal of Aeronautics (ISSN 1000-9361), vol. 2, Nov. 1989, p. 241-246. refs Copyright

The reliability and simplicity of the deformed actuator disk method for predicting blade stall flutter in turbomachinery have been verified. Because the unsteady flow within the cascade channel is neglected in the actuator disk method, errors arise when it is used for computation. A semi-actuator disk method is developed which can be used for stall flutter prediction. This method is shown to be more accurate than the actuator disk method. R.E.P.

**A90-25167\***

**AERODYNAMIC CONTROL OF AIRCRAFT BY FOREBODY VORTEX MANIPULATION**

GERALD N. MALCOLM and T. T. NG (Eidetics International, Inc., Torrance, CA) AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 20 p. refs (Contract F33615-86-C-3623) (AIAA PAPER 90-1827)

Control of aircraft forebody vortices to generate control moments at high angles of attack has been investigated with wind tunnel tests of a generic fighter model. The magnitude and direction of the yawing moment can be controlled by regulating the asymmetric deployment of the strakes or by differential blowing rates from the jets. For the pneumatic system, blowing jets aligned tangential to the surface in either aft or forward directions at 135 deg from windward were very effective. The best method for controlling the yawing moment appears to be to minimize the natural forebody vortex asymmetry with a small pair of tip strakes and utilize blowing to drive the yawing moment away from the symmetric condition. Author

**A90-25185**

**DAMPING OF THE INLET VORTEX IN A TURBOJET ENGINE**

T. GAJEWSKI Journal of Technical Physics (ISSN 0324-8313), vol. 29, no. 3-4, 1988, p. 337-348. refs Copyright

Results are presented from a theoretical investigation of the efficiency of a concept for the damping of turbojet engine inlet vortices by means of a grating. These results establish a framework for the selection of the grating's structural parameters; the integration of the grating into the intake structure is such as to allow retraction during flight. The principal design parameters of the grating are the mounting height and the density and dimensions of the meshes constituting the grating. O.C.

**A90-25200**

**VISCOUS CORRECTIONS ON WINGS IN INCOMPRESSIBLE FLOW**

K. P. SINHAMAHAPATRA and B. C. BASU (Indian Institute of Technology, Kharagpur, India) Aeronautical Journal (ISSN 0001-9240), vol. 94, Feb. 1990, p. 67-72. Research supported by the Ministry of Defence of India. refs Copyright

Numerical methods have been developed to analyze incompressible viscous flows past three dimensional wings with deflected flap using viscous-inviscid interaction techniques. By using a surface transpiration technique, a panel method for external potential flow calculation is combined with a boundary-layer calculation based on an integral method. For the clean wing case, both three-dimensional boundary layer corrections and two-dimensional boundary layer corrections are applied in a strip theory sense and compared with experimental results in the literature. It is found that, for wings with moderate aspect ratio and sweep angle, viscous corrections at low incidences by the two methods are of the same order. Based on this observation, a two-dimensional boundary layer correction method (strip theory sense), including the wake-boundary layer interaction, is developed for the case of wings with a deflected flap of similar planform. Experiments have been conducted to assess the accuracy of the calculation methods for wings with deflected flap; comparison between the experimental and predicted results is encouraging. Author

**A90-25276\*** Massachusetts Inst. of Tech., Cambridge.

**NONLINEAR AERODYNAMICS OF TWO-DIMENSIONAL AIRFOILS IN SEVERE MANEUVER**

JAMES E. MCCUNE, CHUN-MING G. LAM (MIT, Cambridge, MA), and MATTHEW T. SCOTT (Bell Helicopter Textron, Inc., Fort Worth, TX) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 385-393. Previously cited in issue 07, p. 928, Accession no. A88-22091. refs

(Contract AF-AFOSR-86-157; NAG1-658) Copyright

A90-25277#

**COMPARISON OF INVISCID AND VISCOUS SEPARATED FLOWS**

J. A. RHODES (McDonnell Aircraft Co., Saint Louis, MO) and E. VON LAVANTE (Old Dominion University, Norfolk, VA) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 394, 395. Abridged. Previously cited in issue 09, p. 1191, Accession no. A87-24907. refs  
Copyright

A90-25280#

**SHOCK SENSITIVITY IN PARABOLIZED NAVIER-STOKES SOLUTION OF HIGH ANGLE-OF-ATTACK SUPERSONIC FLOW**

D. D. CLINE and G. F. CAREY (Texas, University, Austin) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 406-413. Research supported by Boeing Co. refs  
Copyright

Previous investigations with PNS/shock-fitting algorithms suggest that the lee-side shock profile is overly sensitive to the initial data when the angle of attack becomes large. The nature of this sensitivity is identified in the present work through an eigenvalue analysis of the coefficient matrices of the associated Euler system. These eigenvalues are evaluated along the evolving shock boundary and determine the relative amount of local numerical dissipation in the marching scheme. A significant disparity in the magnitude of the eigenvalues implies highly nonuniform damping of numerical errors along the shock boundary. Using eigenvalue estimates to deduce the PNS stepsize adaptively, and accounting for disparity in the eigenvalues, yields improved predictions of high angle-of-attack supersonic flow as demonstrated in the supporting numerical studies. Shock-profile anomalies encountered by previous investigators can therefore be attributed to an increase in the sensitivity of the PNS solution to the initial data as angle of attack is increased. Author

A90-25283#

**FREE-WAKE ANALYSIS OF COMPRESSIBLE ROTOR FLOWS**

JOHN STEINHOFF and K. RAMACHANDRAN (Tennessee, University, Tullahoma) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 426-431. Research supported by the U.S. Army. Previously cited in issue 09, p. 1193, Accession no. A87-24982. refs  
Copyright

A90-25284#

**A PANEL METHOD FOR ARBITRARY MOVING BOUNDARIES PROBLEMS**

J. Y. YANG (National Taiwan University, Taipei, Republic of China) and Y. J. LEE AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 432-438. refs  
Copyright

The present integral representation of the aerodynamic velocity potential attempts to handle complex geometry in complicated motion, using a ground-fixed frame to describe the governing equations in such a way that the Green's function is in its simplest form in this frame. The integral formulas are expressed as combinations of a surface source operator and its derivatives, in order to furnish a unified method which represents both the scalar wave equations and the Ffowcs William-Hawkins equation; a panel method is then implemented on the basis of the resulting formula and applied to rotating bodies, propeller blades, and a helicopter blade in forward flight. O.C.

A90-25285\*# Ohio State Univ., Columbus.

**EFFECTS OF COMPRESSIBILITY ON THE CHARACTERISTICS OF FREE SHEAR LAYERS**

M. SAMIMY (Ohio State University, Columbus) and G. S. ELLIOTT AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 439-445. refs  
(Contract N00014-87-K-0169; NAG3-764)  
Copyright

A high Reynolds number two-dimensional constant pressure compressible shear layer was formed at the trailing edge of an

0.5 mm-thick splitter plate. Convective Mach numbers of 0.51 and 0.64 were investigated using a two-component coincident LDV for the measurements. For the lower convective Mach number case, the nondimensionalized shear-layer and vorticity thickness growth rates were over 20 percent higher and the momentum thickness growth rate was over 30 percent higher than those of the higher convective Mach number case. The results seen to indicate that both small scale and large scale mixing are reduced with increasing convective Mach number. Author

A90-25288\*# National Aeronautics and Space Administration, Ames Research Center, Moffett Field, CA.

**UNSTEADY AERODYNAMIC AND AEROELASTIC CALCULATIONS FOR WINGS USING EULER EQUATIONS**

GURU P. GURUSWAMY (NASA, Ames Research Center, Moffett Field, CA) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 461-469. Previously cited in issue 13, p. 2000, Accession no. A88-33775. refs  
Copyright

A90-25290\*# Lockheed Aeronautical Systems Co., Marietta, GA.

**TOTAL TEMPERATURE EFFECTS ON CENTERLINE MACH NUMBER CHARACTERISTICS OF FREEJETS**

J. LEPICOVSKY (Lockheed Aeronautical Systems Co., Marietta, GA) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 478-482. refs  
(Contract NAS3-23708)  
Copyright

This paper describes a detailed experimental study of Mach number centerline characteristics of unheated and heated freejets. The jet characteristics were obtained at a range of jet Mach numbers from 0.1 to 0.9 and jet total temperatures up to 900 K. Previously published results showed that the jet total temperature significantly affects the nozzle-exit, boundary-layer characteristics. The results of this study indicate that a strong correlation exists between nozzle-exit, boundary-layer conditions and freejet development. It is clear from this investigation that experimental data on freejet development cannot be meaningfully compared from one facility to another without specific knowledge of nozzle-exit, boundary-layer conditions. It was concluded that direct effect of the jet operating conditions (elevated flow temperature) on freejet development is much less important than the indirect effect due to changed nozzle-exit, boundary-layer characteristics. Author

A90-25292#

**NAVIER-STOKES STUDY OF ROTATING STALL IN COMPRESSOR CASCADES**

F. DAVOUDZADEH, N.-S. LIU, S. J. SHAMROTH, and S. J. THOREN (Scientific Research Associates, Inc., Glastonbury, CT) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 492-498. Previously cited in issue 18, p. 2996, Accession no. A88-44811. refs  
(Contract F33615-84-C-2479)  
Copyright

A90-25301#

**ANALYSIS OF TRANSONIC INTEGRAL EQUATIONS. II - BOUNDARY ELEMENT METHODS**

W. OGANA (Nairobi, University, Kenya) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 556-558. refs  
Copyright

The boundary element solutions of the two-dimensional transonic integral and integrodifferential equations are formulated. Hybrid elements based on constant elements in the streamwise direction and variable elements in the transverse direction are developed which lead to constant-linear and constant-quadratic elements. The boundary-conditions term is computed on the basis of linear and quadratic elements, as well as constant elements; an illustrative computation is conducted for nonlifting parabolic-arc and NACA 0012 airfoils. O.C.

A90-25344#

**NUMERICAL SIMULATION OF VORTEX BREAKDOWN VIA 3-D EULER EQUATIONS**

T. H. LE, P. MEGE (ONERA, Chatillon-sous-Bagneux, France), and Y. MORCHOISNE (Paris VI, Université; ONERA, Chatillon-sous-Bagneux, France) (Turbulence 89, Meeting, Grenoble, France, Sept. 18-21, 1989) ONERA, TP no. 1989-211, 1989, 23 p. Research sponsored by DRET. refs (ONERA, TP NO. 1989-211)

A numerical simulation based on solving three-dimensional Euler equations for an unsteady incompressible flow was carried out as part of a study aimed at modeling vortex breakdown occurring in some aerodynamic configurations at high angle of attack. A continuous formulation with realistic boundary conditions was used, and fourth-order finite difference discretization schemes were implemented. The main known characteristics of the phenomenon, such as three-dimensional structures and unsteadiness, showed up satisfactorily, and the approach used allowed the analysis of the breakdown phenomenon. The scheme was found to be accurate and thus allowed limited discretization, minimizing computing costs. V.L.

A90-25422

**WINGLETS ON ROTOR BLADES IN FORWARD FLIGHT - A THEORETICAL AND EXPERIMENTAL INVESTIGATION**

REINERT H. G. MUELLER Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 31-46. Research supported by DFG. refs Copyright

The influence of an optimized winglet arrangement on the rotor aerodynamics under forward flight conditions is investigated. Using a combination of experimental and theoretical methods it is shown that there are advantages of winglets even in forward flight. Up to high values of the advance ratio, the influence of blade-vortex-interactions can be decreased considerably. This results in lower blade stress and lower noise emission. However, problems occur at high advance ratio on the winglet itself, due to the variation of the angle of attack produced by the forward flight speed. Author

A90-25588

**VORTEX FORMATION AROUND AN OSCILLATING AND TRANSLATING AIRFOIL AT LARGE INCIDENCES**

KAZUO OHMI (Osaka University, Japan), MADELEINE COUTANCEAU (Poitiers, Université, France), TA PHUOC LOC, and ANNIE DULIEU (CNRS, Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur, Orsay, France) Journal of Fluid Mechanics (ISSN 0022-1120), vol. 211, Feb. 1990, p. 37-60. Research supported by DRET. refs Copyright

The starting flows past a two-dimensional oscillating and translating airfoil are investigated by visualization experiments and numerical calculations. The main objects of the present study are to reveal marked characteristics of the unsteady vortices produced from the oscillating airfoil set at large incidences in excess of the static stall angle, and to examine the respective and combined effects of the major experimental parameters on the vortex wake development. The dominant parameter of the flow is the reduced frequency, not only when the airfoil oscillates at incidences close to the static stall angle but also at larger incidences. As the pitching frequency is increased, the patterns of the vortex wake are dependent on the product of the reduced frequency and the amplitude rather than on the frequency itself. It is noted that the combined effect of a high reduced frequency and a large amplitude can give rise to cyclic superposition of leading-edge vortices from which a gradually expanding standing vortex is developed on the upper surface. Author

A90-25589

**EXPERIMENTAL INVESTIGATION OF THREE-DIMENSIONAL TURBULENT BOUNDARY LAYERS ON 'INFINITE' SWEEPED CURVED WINGS**

V. BASKARAN, Y. G. PONTIKIS, and P. BRADSHAW (Imperial College of Science, Technology, and Medicine, London, England)

Journal of Fluid Mechanics (ISSN 0022-1120), vol. 211, Feb. 1990, p. 95-122. Research supported by the Ministry of Defence Procurement Executive. refs Copyright

Mean-flow and turbulence measurements have been made in three-dimensional turbulent boundary layers in curved ducts, simulating adverse pressure gradients on 'infinite' swept curved wing surfaces with concave and convex curvature, respectively. The ratio of the initial boundary-layer thickness to the surface radius of curvature in both cases is approximately 0.01. The results show that the coupled effects of mean flow three-dimensionality and prolonged mild surface curvature of either sign have rather a weak influence on the turbulence structure, unlike the significant influence of extra strain rates when applied individually. In the concave case, the effect of the crossflow appears to oppose the destabilizing effect of curvature in addition to suppressing spanwise wavy inhomogeneities. In contrast, the weak combined influence of convex curvature and crossflow, both of which, separately, tend to attenuate turbulence, implies that the interaction between the two effects is grossly nonlinear. Author

A90-25592

**A SUPERSONIC TURBULENT BOUNDARY LAYER IN AN ADVERSE PRESSURE GRADIENT**

EMERICK M. FERNANDO and ALEXANDER J. SMITS (Princeton University, NJ) Journal of Fluid Mechanics (ISSN 0022-1120), vol. 211, Feb. 1990, p. 285-307. refs (Contract AF-AFOSR-85-0126; AF-AFOSR-88-0120) Copyright

This investigation describes the effects of an adverse pressure gradient on a flat plate supersonic turbulent boundary layer. Single normal hot wires and crossed wires were used to study the Reynolds stress behavior, and the features of the large-scale structures in the boundary layer were investigated by measuring space-time correlations in the normal and spanwise directions. Both the mean flow and the turbulence were strongly affected by the pressure gradient. However, the turbulent stress ratios showed much less variation than the stresses, and the essential nature of the large-scale structures was unaffected by the pressure gradient. The addition of streamline curvature affects the turbulence strongly, although its influence on the mean velocity field is less pronounced and the modifications to the skin-friction distribution seem to follow the empirical correlations developed by Bradshaw (1974). Author

A90-25597

**A GENERALIZED LIFTING-LINE THEORY FOR CURVED AND SWEEPED WINGS**

JEAN-LUC GUERMOND (Bassin d'Essais des Carenes, Paris, France) Journal of Fluid Mechanics (ISSN 0022-1120), vol. 211, Feb. 1990, p. 497-513. Research supported by the Ministère de la Défense Marine. refs Copyright

A generalized lifting-line theory is developed in inviscid, incompressible, steady flow for curved, swept wings of large aspect ratio. By using the integral formulation of the problem instead of the partial differential equation formulation, it is possible to circumvent the algebraic complications encountered by the previous approaches using the method of the matched asymptotic expansions. At each approximation order the problem is reduced to inverting a classical Carleman type integral equation. The asymptotic solution in terms of circulation is found to be very convenient for illustrating the major three-dimensional effects induced on the flow by curvature and yaw angle. The concept of the finite part integrals, introduced by Hadamard (1932), is shown to be very useful for handling elegantly singularities. Comparisons of the new, simple approach with lifting-surface theories reveal excellent agreements in terms of circulation. Furthermore, a consistent calculation of the three components of the total force acting on the wing is done in the lifting-line context without reintroducing the inner geometry of the wing. Author

### A90-25730#

#### ON EFFICIENCY AND ACCURACY OF NUMERICAL METHODS FOR SOLVING AERODYNAMIC EQUATIONS

DEXUN FU (Chinese Academy of Sciences, Institute of Mechanics, Beijing, People's Republic of China) and YANWEN MA (Beijing Institute of Aerodynamics, People's Republic of China) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 86-91. Research supported by the National Natural Science Foundation of China.

The application of time-dependent methods to the numerical simulation of steady flows is considered analytically, reviewing the results of the authors' recent investigations. Particular attention is given to the construction of implicit schemes, modifications with operator addition, approximate factorization with special matrix splitting, nested iterative procedures, and the treatment of shocks and vortex sheets. Typical numerical results are presented in graphs. T.K.

### A90-25732#

#### A HIGH-ORDER TIME-ACCURATE SCHEME AND ITS APPLICATIONS

KENICHI MATSUNO (National Aerospace Laboratory, Tokyo, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 104-109. refs

The numerical technique developed by Matsuno (1987 and 1989) to solve the complete Navier-Stokes equations for two-dimensional unsteady flow is described and demonstrated. The derivation of the iterative algorithm is outlined; the finite-volume numerical implementation is explained; and third-order time-accurate results are presented in graphs for typical problems involving flows on NACA 0012 airfoils: (1) steady inviscid flow at Mach 0.8 and angle of attack 1.25 deg, (2) unsteady laminar flow at Mach 0.4 and angle of attack 15 deg (Reynolds number 10,000), and (3) unsteady turbulent flow at Mach 0.3 and angle of attack 25 deg (Reynolds number 10 to the 6th). T.K.

### A90-25739#

#### THE TRANSONIC NONISENTROPIC POTENTIAL CALCULATION

ZI-QIANG ZHU and XUE-SONG BAI (Beijing University of Aeronautics and Astronautics, People's Republic of China) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 153-158. refs

The extension of numerical solution techniques based on the full potential equations to nonisentropic flows is considered analytically. The main features of the full potential method are reviewed; the corrections for entropy and vorticity are explained; and a new formulation based on an entropy shock-point operator is derived. Numerical results for two- and three-dimensional simulations of flows on wings and wing bodies are presented in graphs; it is shown that the present nonisentropic potential method gives results in good general agreement with Euler computations or experimental data while requiring computation times comparable to those of the full potential method. T.K.

### A90-25771#

#### COMPUTATION OF STEADY THREE DIMENSIONAL TRANSONIC INTERNAL FLOWS

ANDREA DADONE and BERNARDO FORTUNATO (Bari, Università, Italy) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 359-364. Research supported by MPI and CNR. refs

An efficient Euler solver for three-dimensional transonic internal flows is presented which reduces a multidimensional flow to a sequence of simple and quasi-one-dimensional problems; in

addition, it fits shocks by means of a straightforward technique. Three illustrative treatments of a given channel flow configuration, namely a two-dimensional plane channel with a circular bump and variable inlet conditions, demonstrate the simplicity, the high convergence rate, and the shock structure regularity over grid-line crossings which characterize the method. O.C.

### A90-25772#

#### CALCULATION OF TIP LEAKAGE FLOW WITH THREE-DIMENSIONAL EULER CODE

MAKOTO YAMAMOTO (Ishikawajima Harima Heavy Industries Co., Ltd., Tokyo, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 365-370. refs

The results obtained by the present transonic compressor rotor tip-leakage flow simulation, which attempted to predict the interaction between tip-leakage and mainstream flows by means of a three-dimensional Euler code, have been compared with both experimental results and the computational results of Dawes (1987). The three-dimensional Euler code is that of Denton (1985), which yields the fastest of the currently obtainable convergence rates. Greater success is obtained for the flow in the rotor blading than in the stator blading; the roll-up of the tip-leakage vortex must be reproduced. O.C.

### A90-25773#

#### FLOW-CALCULATION OVER A DELTA-WING USING THE THIN-LAYER NAVIER-STOKES EQUATIONS

ANAND KUMAR (National Aeronautical Laboratory, Bangalore, India) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 371-376. Research supported by the Aeronautical Development Agency. refs

The vortex flow over a round leading-edge delta wing is presently computed by means of a three-dimensional, laminar, thin-layer Navier-Stokes solver which employs finite volume spatial discretization and Runge-Kutta time integration. The results thus obtained are compared with those of experiments and of an Euler simulation. The Navier-Stokes code proceeds on a 64 x 24 x 32 grid of 0-0 topology. Flow is computed for a freestream Mach number of 0.85, at 10-deg angle of incidence. Pressure trends and primary and secondary vortices are found to be well predicted. O.C.

### A90-25777#

#### NON-EQUILIBRIUM HYPERSONIC FLOWS - PHYSICS AND NUMERICS

MAURIZIO PANDOLFI (Torino, Politecnico, Turin, Italy) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 435-440.

Some features of the chemical nonequilibrium phenomena that occur in hypersonic flows of air are studied analytically. The Euler equations are used to describe the fluid dynamics. The analysis is based on the species O, N, NO, O<sub>2</sub> and N<sub>2</sub>. C.D.

### A90-25783#

#### NUMERICAL CALCULATION OF BUBBLY TWO PHASE FLOW AROUND AN AIRFOIL

HIDEJI NISHIKAWA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tanashi, Japan), YOICHIRO MATSUMOTO, and HIDEO OHASHI (Tokyo, University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 471-476.

A new method based on the MacCormack (1969) method is combined with a boundary-conforming curvilinear coordinate system to solve the bubbly two-phase flow around an airfoil. The effect of slip velocity is found to be important in calculating the flow.



The method is efficient for analysis of bubbly two-phase flow around an arbitrary object, and the results can be applied to the analysis of pump performance under bubbly two-phase conditions. C.D.

#### A90-25795#

##### **NUMERICAL SIMULATIONS OF UNSTEADY SHOCK REFLECTIONS BY RAMPS**

SHIGERU ASO, MASANORI TAKANO (Kyushu University, Fukuoka, Japan), ANZHONG TAN (Chinese Academy of Sciences, Institute of Mechanics, Beijing, People's Republic of China), and MASANORI HAYASHI (Nishinippon Institute of Technology, Fukuoka, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 543-547. refs

One of the most important problems for the design of high-speed winged vehicles is the severe aerodynamic heating and pressure rise caused by impingement of shock waves on surfaces. In this paper, this problem is simulated numerically by solving the two-dimensional Euler equations by a TVD scheme of Harten (1983) with a modified flux approach and resolution enhancement by artificial compression. Calculations are performed for regular reflections, single Mach reflections, complex Mach reflections, and double Mach reflections. Then, the thin-layer Navier-Stokes equations are solved to predict aerodynamic heating. The TVD scheme is used for the convection terms and the conventional central differences are used for the viscous terms. The results show excellent agreement with experimental findings. The additional peak heating caused by impingement of the slip layer is especially well predicted. C.D.

#### A90-25796#

##### **NUMERICAL METHODS FOR TRANSONIC CASCADE FLOW PROBLEMS**

H. DAIGUJI and S. YAMAMOTO (Tohoku University, Sendai, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 548-553. refs

In this paper, implicit, time-marching, finite-difference schemes for the Euler and Navier-Stokes (NS) equations using the momentum equations of contravariant velocities are first briefly explained. Then, two-dimensional Euler and NS analyses of the compressor and turbine cascades using the k-epsilon model taking account of the low Reynolds number effects are described. Finally, the NS direct simulations of three-dimensional flow through axial flow compressors and turbine rotor are discussed. C.D.

#### A90-25797#

##### **NAVIER-STOKES SIMULATIONS AROUND A HIGH-SPEED PROPELLER**

CHUICHI ARAKAWA (Tokyo, University, Japan), SHIGERU SAITO, HIROSHI KOBAYASHI (National Aerospace Laboratory, Chofu, Japan), and YUICHI MATSUO IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 554-559. refs

A three-dimensional Navier-Stokes code has been developed in conjunction with a high-accuracy TVD scheme and a two-equation turbulence model have been developed and applied to analyze the flow around a single-rotation high-speed propeller and to predict its aerodynamic performance. The code shows improved accuracy in characterizing the shock wave with no added artificial dissipation and can also resolve more clearly the behavior of the three-dimensional turbulent boundary layer. The viscous flow structures around the propeller, including viscous flow features such as shock/boundary-layer interaction, boundary layer separation, and vortical motions, are shown with greater clarity. The predicted aerodynamic performance is in good agreement with experimental data. C.D.

#### A90-25798#

##### **ANALYSIS OF THREE-DIMENSIONAL AEROSPACE CONFIGURATIONS USING THE EULER AND NAVIER-STOKES EQUATIONS**

U. HERRMANN, N. KROLL, R. RADESPIEL, C. C. ROSSOW, J. SCHOENE (DLR, Institut fuer Entwurfsaerodynamik, Brunswick, Federal Republic of Germany) et al. IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 560-565. refs

Applications of a cell-vertex finite volume method to three-dimensional aerospace configurations are presented. The transonic flow around a low-aspect ratio wing was calculated by solving the Navier-Stokes equations. Using the Johnson-King turbulence model, excellent agreement with measurements is achieved even for separated flow, and very good convergence rates are obtained using the multigrid technique. Since the multigrid technique did not improve the efficiency for supersonic flows, the latter were calculated in the single grid mode. Results from the calculations of inviscid three-dimensional flows with attached shocks as well as with bow shocks were compared with measurements; the results confirmed by validity of calculating supersonic flows by solving the Euler equations. The applicability of the present Euler code is further demonstrated by calculating the supersonic flow around the Hermes reentry vehicle and around the forebody of a generic hypersonic aircraft. C.D.

#### A90-25800#

##### **NUMERICAL AERODYNAMICS VIA FORMAL INTEGRATION - LAPLACE, EULER, PRANDTL, NAVIER-STOKES AND REYNOLDS EQUATIONS**

FRED R. PAYNE (Texas, University, Arlington) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 572-577. refs

Some experiences with the cited quintet of fluid dynamical equations are discussed. Applications over the past decade of a direct and formal integral methodology span from simple test cases to subsonic and supersonic boundary-layers, atmospheric 'micro-bursts,' turbulent wake and boundary-layer flows, Bernard stability, nonlinear heat conduction, Maxwell's equations and population dynamics. The method has been a unifying influence upon a host of dissimilar problems; additionally, it is highly compatible with computing machinery since it minimizes the 'bad' arithmetic operations of division and subtraction. Further, even if the final stage, namely the numerics, of 'DFI' (Direct, Formal Integration) is not implemented its mathematical formalism will generate new insights into the problem at hand. Comparisons to alternate differential equation solvers are made. Author

#### A90-25804#

##### **NUMERICAL STUDY OF THREE METHODS FOR SOLVING REACTING FLOWS**

AHMAD A. M. HALIM (USAF, Institute of Technology, Wright-Patterson AFB, OH) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 596-604. refs

Three models for performing nonequilibrium flow field calculations are studied. Model I is based on the numerical solution of the full equation for the flow and the chemistry; model II is based on the numerical solution of an approximate form of the equations for the flow and the chemistry; and model III is based on the numerical solution of the boundary layer equations for the flow and the chemistry. Stoichiometric relations and the law of mass action are examined. It is noted that model I requires a large amount of computer time, model II is very fast and requires little computer time, and model III is simple and fast. I.F.



**A90-25809#**

### COMPUTATIONAL AND EXPERIMENTAL ANALYSIS OF TRANSONIC FANJET ENGINE FLOW FIELD USING 3-D EULER CODE

NAOKI HIROSE, KEISUKE ASAI (National Aerospace Laboratory, Chofu, Japan), KATUYA IKAWA, and RYUMA KAWAMURA (Nihon University, Funabashi, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 635-640. refs

A three-dimensional Euler code for fan-jet engine and Turbine Powered Simulator (TPS) wind tunnel testing were developed utilizing MacCormack's FVM scheme to confirm the validity of TPS testing method. The results were compared with the wind tunnel experimental data for an axisymmetric TPS configuration. The effects of difference between the real engine and TPS were analyzed. Three-dimensional flow analysis shows the angle of attack effects in inlet flow field and jet exhaust plume. Author

**A90-25820#**

### TURBULENCE MODELS FOR 3D TRANSONIC VISCOUS FLOWS. II

YOKO TAKAKURA (Fujitsu, Ltd., Tokyo, Japan), SATORU OGAWA, and TOMIKO ISHIGURO (National Aerospace Laboratory, Tokyo, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 729-734. refs

The performance of four different turbulence models is evaluated in numerical simulations of three-dimensional viscous flows on the ONERA M6 wing at freestream Mach number 0.87, angle of attack 6.06 deg, and Reynolds number  $1.17 \times 10^6$  to the 7th. The predicted pressure contours, streamlines, and Cp distributions are presented graphically and compared with experimental data. It is shown that the improved subgrid-scale turbulence model of Deardorff (1970) and the k-epsilon model of Jones and Launder (1972) give generally more accurate results than the model of Baldwin and Lomax (1978). Good agreement is found between the Cp distributions of the k-epsilon model and the more detailed turbulence model of Johnson and King (1985). T.K.

**A90-25823#**

### THREE-DIMENSIONAL SIMULATIONS OF HYPERSONIC FLOWS

M. PFITZNER, C. WEILAND, and G. HARTMANN (MBB GmbH, Munich, Federal Republic of Germany) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 755-760. refs

The development of new space transportation systems and of hypersonic aircraft requires the simulation of high-speed air flows about realistic configurations. New concepts of propulsion systems have to be studied, and the numerical simulation of the flowfields can lead to new insights. The high temperatures which appear in those flows require real-gas effects to be taken into account. Here, several simulations of inviscid supersonic and hypersonic ideal-gas and real-gas flows are presented. These include simulations of the full inviscid flowfield about the Hermes reentry body and a hypersonic aircraft as well as flow studies of an expansion nozzle. Author

**A90-25827#**

### A NUMERICAL METHOD FOR SOLVING THE UNSTEADY COMPRESSIBLE NAVIER-STOKES EQUATIONS

S. YAMAMOTO and H. DAIGUJI (Tohoku University, Sendai, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 779-784. refs

The implicit time-marching method developed by Yamamoto et

al. (1988) and Daiguji and Yamamoto (1988) to solve the three-dimensional Navier-Stokes equations for compressible flow is extended to study the unsteady flow in the stator-rotor of an axial-flow turbine. The approach is based on the momentum equations of the contravariant velocities and combines Newton iteration, a modified H-type grid, and a k-epsilon turbulence model. The derivation of the fundamental equations is reviewed; the numerical algorithm is outlined; and results for typical two-dimensional problems are presented graphically. The method is shown to reproduce significant flow features such as the unsteadiness of the stator-blade wakes, shocks near the rotor trailing edges at transonic velocities, and static pressure fluctuations at the rotor surface. T.K.

**A90-25831#**

### FLOW DEPENDENT GRID FOR AERODYNAMIC DESIGNERS

KAZUO KIKUCHI (National Aerospace Laboratory, Tokyo, Japan), HIROAKI ASAH, KENJI MORI, TADAO HASHIMOTO, ATSUSHIGE TANAKA (Ishikawajima-Harima Heavy Industries Co., Ltd., Tokyo, Japan) et al. IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 803-807.

An iso-mass-flow-rate iso-total-pressure adaptive grid-generation scheme for flow simulations based on the Navier-Stokes equations is developed analytically and demonstrated. The principle of minimization within a grid unit is explained; the grid-generation procedure is outlined; and results are presented in graphs for an HP turbine blade at Reynolds number 916,500, inlet Mach number 0.196, outlet Mach number 0.957, and inlet temperature and pressure 382.35 K and 185.5 kPa, respectively. The flow-dependent grid is shown to be uniquely determined, to concentrate grid lines near the shock region, and to satisfy the requirement of smooth periodicity. T.K.

**A90-25835#**

### TRANSONIC AERODYNAMICS ANALYSIS OF UNCONVENTIONAL WING CONFIGURATIONS BY 3D-EULER CODE

MASAKATA HASHIMOTO (Mitsui Engineering and Shipbuilding Co., Ltd., Tokyo, Japan), NAOKI HIROSE, and TAKESHI OHNOKI (National Aerospace Laboratory, Chofu, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 825-830. refs

Transonic aerodynamic analyses of aircraft wing configurations using the three-dimensional, time-split MacCormack's scheme for the Euler equations are presented. The wings considered include the conventional swept-back wing and the unconventional forward-swept and joined wings. It is concluded that the results are promising. C.D.

**A90-25836#**

### NAVIER-STOKES COMPUTATIONS FOR THE INVESTIGATION OF FLOWFIELDS ABOUT A SPACE-PLANE

KISA MATSUSHIMA (Fujitsu, Ltd., Tokyo, Japan), SUSUMU TAKANASHI (National Aerospace Laboratory, Tokyo, Japan), and KOZO FUJII (Institute of Space and Astronautical Science, Kanagawa, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 831-836. refs

The present Navier-Stokes code for simulating viscous flows about the planned Japanese Space Plane at high angles of attack is validated here by comparing its solutions with experimental results. A detailed numerical study of the flowfields using graphic techniques is reported. The aerodynamic effect of the flow phenomena on the performance of the Space Plane is discussed. C.D.

A90-25846#

**NUMERICAL SIMULATION OF SEPARATED FLOWS AROUND A WING SECTION BY A DISCRETE VORTEX METHOD**

SHIGERU ASO, ATSUSHI FUJIMOTO (Kyushu University, Fukuoka, Japan), MASANORI HAYASHI (Nishinippon Institute of Technology, Fukuoka, Japan), and NAOKI FUTATSUDERA (Mitsubishi Heavy Industries, Ltd., Nagoya, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 897-902. refs

The separated flows around wing sections are calculated by a method in which the body is expressed by a set of linearly distributed vortex sheets and the separated shear layer is expressed by a row of discrete vortices. New procedures for estimating the pressure coefficient are proposed. The calculated results show good agreement with experimental ones. The method can also be used to simulate separated flows around pitching wing sections and can be applied to complicated flow fields.

C.D.

A90-25863#

**NUMERICAL SIMULATION OF WING IN GROUND EFFECT**

TETUYA KAWAMURA and SHOZO KUBO (Tottori University, Koyama, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1037-1042.

The flow around a winged ground-effect vehicle is studied by numerical simulation, and the results are used to reform the vehicle shape. The vehicle cruising speed is taken to be between 100 km/hr and 500 km/hr depending on size. Both compressible and incompressible Navier-Stokes equations are solved in order to verify the solution. A new numerical scheme for simulating the compressible flow is presented.

C.D.

A90-25871#

**PREDICTION OF TIP-CLEARANCE EFFECTS ON A WING BY THE PANEL METHOD**

JANG-SOO CHOI and YOSHIYUKI SUGIYAMA (Nagoya University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1126-1131.

To study the effect of tip-clearance on the aerodynamic characteristics of a wing, the flow around a rectangular wing lying with clearance between two plate walls was calculated by the first-order panel method. The computational results, even though they are obtained under the ideal flow, show the same behaviors as the experimental data. For instance, the pressure distribution over whole wing, the rapid increase of local lift and drag curves near wing-tip, and the existence of higher circulation near the wing-tip for the smaller tip-clearance, show the same tendencies as the experimental results.

Author

A90-25935\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**EXPERIMENTAL STUDIES OF 90 DEG CORNER CASCADES IN THE NATIONAL FULL-SCALE AERODYNAMIC COMPLEX**

LARRY A. MEYN (NASA, Ames Research Center, Moffett Field, CA) AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 7 p. (AIAA PAPER 90-1826)

Two 90 deg, fixed geometry, turning vane cascades were replaced in the 40- by 80-foot wind tunnel circuit of the National Full-Scale Aerodynamic Complex as a part of a major facility upgrade. Prior to the replacement of these vanes, small-scale, two-dimensional tests were conducted to assess the aerodynamic performance of the original, 1930's technology vane geometry and a new vane geometry which was developed using a modern cascade design code. The small scale tests were conducted in the 1/10th-Scale Cascade Test Facility and included measurements of total pressure, static pressure, and flow angularity distributions

in the wake of the cascade and static pressure distributions along the vane profiles. Test results and a detailed comparison of the two vane designs are presented. Based on these results, the new design was chosen and subsequently installed in the wind tunnel. During the integrated systems test of the upgraded facility, two of the 52 vanes in the first cascade were instrumented near midspan. The full-scale test results are presented, these show the cascade pressure loss coefficient to be slightly larger than obtained in the small-scale tests. Elements of the three-dimensional flow field upstream of the cascade, which effect can impact cascade performance, are discussed and recommendations for future research are given.

Author

A90-26067

**VORTEX DYNAMICS OF DELTA WINGS**

MARIO LEE and CHIH-MING HO (Southern California, University, Los Angeles, CA) IN: Frontiers in experimental fluid mechanics. Berlin and New York, Springer-Verlag, 1989, p. 365-427. refs (Contract F49620-85-C-0080)

Copyright

Experimental results for delta wings are reviewed. The review is made from the perspective of fundamental fluid dynamic mechanisms. In particular, the balance between vorticity generation on the surface and freestream convection of it is used to understand how different parameters affect the leading edge vortices which dominate the aerodynamics of a delta wing at high angles of attack.

Author

A90-26128\*# Purdue Univ., West Lafayette, IN.

**PROPELLER-WING INTERACTION USING A FREQUENCY DOMAIN PANEL METHOD**

MARC H. WILLIAMS (Purdue University, West Lafayette, IN) and JINSOO CHO Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 196-203. refs (Contract NAG3-499)

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The unsteady aerodynamic coupling between a propeller and a wing is analyzed using linear compressible aerodynamic theory. The periodic loads are decomposed into harmonics, and the harmonic amplitudes are found iteratively. Each stage of the iteration involves the solution of an isolated propeller or wing problem; the interaction is done through the Fourier transform of the induced velocity field. The method was validated by comparing the predicted velocity field about an isolated propeller with detailed laser Doppler velocimeter measurements and by comparison with mean loads measured in a wing-propeller experiment. Comparisons have also been made between the fluctuating loads predicted by the present method and a quasisteady vortex lattice scheme.

Author

A90-26129\*# Analytical Services and Materials, Inc., Hampton, VA.

**DESIGN OF LOW REYNOLDS NUMBER AIRFOILS. I**

W. PFENNINGER and C. S. VEMURU (Analytical Services and Materials, Inc., Hampton, VA) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 204-210. Previously cited in issue 16, p. 2597, Accession no. A88-40765. refs (Contract NAS1-18235)

A90-26130\*# Ohio State Univ., Columbus.

**MEASUREMENTS ON AN OSCILLATING 70-DEG DELTA WING IN SUBSONIC FLOW**

M. R. SOLTANI, M. B. BRAGG (Ohio State University, Columbus), and J. M. BRANDON (NASA, Langley Research Center, Hampton, VA) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 211-217. Previously cited in issue 16, p. 2595, Accession no. A88-40745. refs (Contract NAG1-641)

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A90-26132#

**EFFICIENT METHOD FOR COMPUTING TRANSONIC AND SUPERSONIC FLOWS ABOUT AIRCRAFT**

## 02 AERODYNAMICS

G. VOLPE (Grumman Corporate Research Center, Bethpage, NY) and A. JAMESON (Princeton University, NJ) (ICAS, Congress, 16th, Jerusalem, Israel, Aug. 28-Sept. 2, 1988, Proceedings. Volume 2, p. 1224-1236) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 223-231. Previously cited in issue 03, p. 259, Accession no. A89-13624. refs  
Copyright

**A90-26135\*#** Old Dominion Univ., Norfolk, VA.  
**APPLICATION OF MULTIPLE GRIDS TOPOLOGY TO SUPERSONIC INTERNAL/EXTERNAL FLOW INTERACTIONS**  
M. KATHONG, S. N. TIWARI (Old Dominion University, Norfolk, VA), and R. E. SMITH (NASA, Langley Research Center, Hampton, VA) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 245-252. Previously cited in issue 20, p. 3342, Accession no. A88-48794. refs  
(Contract NCC1-68)  
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**A90-26136\*#** Vigyan Research Associates, Inc., Hampton, VA.  
**FOURTH-ORDER ACCURATE THREE-DIMENSIONAL COMPRESSIBLE BOUNDARY-LAYER CALCULATIONS**  
VENKIT IYER (Vigyan Research Associates, Hampton, VA) and JULIUS E. HARRIS (NASA, Langley Research Center, Hampton, VA) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 253-261. Previously cited in issue 09, p. 1273, Accession no. A89-25115. refs  
(Contract NAS1-17919)  
Copyright

**A90-26137\*#** Ohio State Univ., Columbus.  
**MEASURED FORCES AND MOMENTS ON A DELTA WING DURING PITCH-UP**  
M. B. BRAGG and M. R. SOLTANI (Ohio State University, Columbus) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 262-267. refs  
(Contract NAG1-641)  
Copyright

A series of low-speed wind tunnel tests on a 70-deg, sharp, leading-edge delta wing undergoing ramp pitching motion of high amplitude were performed to investigate the aerodynamic forces and moments. Forces and moments were obtained from a six-component internal balance. Large amplitude oscillatory motion was produced by sinusoidally oscillating the model over a range of reduced frequencies. Ramp motion was produced by pitching the model through a half cycle of sinusoidal motion at a root chord Reynolds number of 1.54 million. The effect of ramp and oscillatory motions on the forces and moments are almost identical at matched pitch rates. Pitch rate had strong effect on the magnitude of the aerodynamic forces and moments. Upon completion of the model motion, some time is required for the forces and moments to decay to their static values. This convergence of the dynamic values to the static ones was a function of the pitch rate. Author

**A90-26141#**  
**EFFECTS OF A CONTOURED APEX ON VORTEX BREAKDOWN**  
RONALD L. PANTON (Texas, University, Austin) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 285-288. Research supported by Lockheed Advanced Aeronautics Co. and General Dynamics Corp. Previously cited in issue 09, p. 1274, Accession no. A89-25168. refs  
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**A90-26341#**  
**NUMERICAL PREDICTION OF WAKES OF DIFFERENT BODIES**  
V. RAMJEE, J. L. NARASIMHAN, and PHILIP M. DIWAKAR (Indian Institute of Technology, Madras, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 375-380. Research supported by the Aeronautics Research and Development Board. refs

Measurements of the mean velocity were carried out in the wake of an airfoil (NACA 0012) and also of a rectangular cylinder placed in a straight duct. The most important parameters (wake width and velocity defect) have been computed in the intermediate and far wake regions. The results were predicted using two computer programs (Patankar-Spalding method and GENMIX) incorporating the k-epsilon model, meant for parabolic phenomena. The numerical procedures were seen to predict fairly well the intermediate wakes of the two different bodies. Author

**A90-26347#**  
**OPTIMAL REFLEX CAMBER**  
S. C. GUPTA (Institute of Armament Technology, Poona, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 427-429. Research supported by the Institute of Armament Technology.

A model is presented for determining the camber that will yield minimum drag for a given wing planform, flight Mach number, lift, and specified pitching moment. The model is based on linearized theory and is restricted to planar wing systems. The method is used to determine the optimal reflex and optimal nonreflex camber for the case of crank-crop-delta wings. R.B.

**A90-26349#**  
**SIMULATION OF SEPARATED FLOWS USING PANEL METHOD**

B. K. MURALI (SVR College of Engineering and Technology, Surat, India) and G. R. SHEVARE (Indian Institute of Technology, Bombay, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 435-438. refs

A panel method is used for the simulation of separated flows over an object. The paper starts with a brief survey of inviscid simulation of separated flows followed by the theoretical model used in this paper. Three different problems, namely flow over a flat plate, flow past a flame holder and flow past a pair of plates, have been taken up for the analysis. The methodology is validated for the case of flow over a flat plate. Finally the results are presented and discussed for the cases considered for the simulation. Author

**A90-26478\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**KNOWLEDGE-BASED FLOW FIELD ZONING**  
ALISON E. ANDREWS (NASA, Ames Research Center, Moffett Field, CA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 13-22. Previously announced in STAR as N88-30314. refs  
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Automation flow field zoning in two dimensions is an important step towards easing the three-dimensional grid generation bottleneck in computational fluid dynamics. A knowledge based approach works well, but certain aspects of flow field zoning make the use of such an approach challenging. A knowledge based flow field zoner, called EZGrid, was implemented and tested on representative two-dimensional aerodynamic configurations. Results are shown which illustrate the way in which EZGrid incorporates the effects of physics, shape description, position, and user bias in a flow field zoning. Author

**A90-26480**  
**ALGEBRAIC BOUNDARY-CONFORMING GRID GENERATION AROUND WING/TAIL-BODY CONFIGURATIONS**  
M. M. ALISHAHI (Shiraz, University, Iran) and M. FARID IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 31-40. refs  
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A computer program has been developed for three-dimensional grid generation around wing-body and tail-body configurations. Various wing sections and planforms, different nose and afterbody

shapes can be interactively chosen. Two different topologies of C-O and H-O type have been used to generate the desired three-dimensional body-conforming grid. In H-O topology there is a singularity of polar type and a remedy has been introduced to remove this kind of singularity. Using various blending functions, transfinite interpolation in three-directions have been applied to generate the grids. It is shown that H-O topology is better fitted for grid generation around cruciform tail-body shapes while C-O topology is better suited for wing-tail-body configurations without any vertical panel. Author

**A90-26494****EFFECT OF THE GRID SYSTEM ON THE SOLUTION OF EULER EQUATIONS**

KLAUS A. HOFFMANN, TING-LUNG CHIANG, and JOHN J. BERTIN (Texas, University, Austin) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 185-194. refs Copyright

A numerical code for solving the Euler equations has been developed. The scheme is based on the Steger and Warming flux vector splitting method and approximate factorization. The boundary conditions are implemented implicitly, thereby allowing use of large time steps. The steady state solution is obtained by time marching from a uniformly imposed initial flow field. Solutions are obtained for various axisymmetric configurations using three grid generators which include algebraic, elliptic, and surface normal grid generators. The effect of various grid systems on convergence and accuracy is investigated. In addition, the grid point distribution and its effect on the convergence of the solution is presented. Author

**A90-26496****SURFACE GRID GENERATION THROUGH ELLIPTIC PDES**

Z. U. A. WARSI and W. N. TIARN (Mississippi State University, Mississippi State) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 207-216. refs (Contract AF-AFOSR-85-0143) Copyright

The problem of numerical grid generation in arbitrary surfaces through elliptic partial differential equations (PDEs) has been considered for application to practical shapes of engineering interest. An important problem in the execution of the proposed algorithm is in the representation of the surface on the basis of the given Cartesian data points. In this regard the methods of overlapping least squares and the Fourier analysis of the section curves of the body have been developed and then used to solve the grid generation problem for a complete airplane surface. A new method of deriving the basic grid generation PDE's has also been given. Author

**A90-26498****A SEMI-ANALYTICAL PROCEDURE FOR THE CONFORMAL MAPPING OF ARBITRARY AIRFOIL CONTOURS**

H. SCHUETZ and F. THIELE (Berlin, Technische Universitaet, Federal Republic of Germany) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 227-236. refs Copyright

For an arbitrarily shaped body the accuracy of a Navier-Stokes solver strongly depends on the generation of the numerical grid. Conformal mapping techniques allow an accurate transformation of partial differential equations to general curvilinear coordinates. Unlike previous mapping methods a semianalytical procedure is proposed for the conformal transformation of the Navier-Stokes equations. The application of the procedure is demonstrated to calculate the unsteady flow around a NACA 4412 airfoil at 15 deg angle of attack and  $Re = 1000$ . Author

**A90-26507****A COMPARISON OF TWO ADAPTIVE GRID TECHNIQUES**

JOHN F. DANNENHOFFER, III (United Technologies Research Center, East Hartford, CT) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 319-328. refs Copyright

In recent years, numerical analysts have increasingly turned toward adaptive grid techniques to efficiently obtain highly-accurate solutions to partial-differential equations. This paper presents a comparison of two distinct grid adaptation approaches, grid-point redistribution and grid-embedding, applied to two-dimensional, steady, inviscid, shocked flows. Grid redistribution is accomplished through a control function approach applied to the elliptic grid-generator while the embedding approach consists of a fixed global grid and an automatically-chosen number of irregularly-shaped, embedded regions. For both techniques, the Euler flow equations are integrated to steady-state using Ni's Lax-Wendroff-type integrator to predict the flow fields in ducts and about isolated airfoil configurations. The application of a common integration scheme as well as a common adaptive control function leads to a direct comparison of the effectiveness of the two adaptation approaches for the types of problems tested. Author

**A90-26508****SOLUTION-ADAPTIVE GRIDS FOR TRANSONIC FLOWS**

D. CATHERALL (Royal Aerospace Establishment, Farnborough, England) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 329-338. refs Copyright

A description is given of a method which uses the current numerical solution on a given structured computational grid to re-position the nodes of the grid so as to cluster them where solution activity is high, while retaining a high degree of grid regularity. Each grid line is adapted in turn, utilizing a spring analogy, with controls being applied to correct grid cross-overs, adjust minimum spacing, and limit grid expansion rates. Examples are given of inviscid and viscous flows around aerofoils, and of inviscid flows around wings. The procedure may be used to achieve grid point economies, or to produce high quality grids and solutions from initially indifferent ones. Author

**A90-26513****THE CONSTRUCTION OF COMPONENT-ADAPTIVE GRIDS FOR AERODYNAMIC GEOMETRIES**

J. A. SHAW, J. M. GEORGALA (Aircraft Research Association, Manton Lane, England), and N. P. WEATHERILL (Swansea, University College, Wales) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 383-394. Research supported by the Ministry of Defence Procurement Executive. refs Copyright

A multiblock grid generation technique is described. An algorithm for creating component-adaptive block topologies, from schematic representations of aerodynamic geometries, is outlined. Techniques for controlling the resulting grids, generated as the solution of a set of non-linear elliptic partial differential equations are described. Grids for a variety of military aircraft are shown. Finite-volume based solutions of the Euler equations are compared with experimental data. Author

**A90-26526****TECHNIQUES IN MULTIBLOCK DOMAIN DECOMPOSITION AND SURFACE GRID GENERATION**

S. E. ALLWRIGHT (British Aerospace, PLC, Bristol, England) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach,

## 02 AERODYNAMICS

FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 559-568.

Copyright

Recent advances in multiblock grid-generation methods for complex aerodynamic configurations are reviewed. Topics addressed include the basic principles of multiblock grid generation, graphical and automatic approaches to block decomposition, control of grid-point spacing, and surface-grid generation by the method of Thompson et al. (1974). Multiblock surface and field grids for a civil transport aircraft and an executive jet are shown.

T.K.

### A90-26527

#### APPLICATION OF A MULTIBLOCK GRID GENERATION APPROACH TO AIRCRAFT CONFIGURATIONS

A. KLUNOVER, T. J. KAO, and N. J. YU (Boeing Co., Seattle, WA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 569-578. refs

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A multiblock grid-generation method, as applied to complex airplane geometry, is presented. The process is based on a partnership between an interactive graphics package for defining geometry and boundaries and a numerical system for generating the field grid. Several test cases illustrate this two-step procedure and show some of its capabilities.

Author

### A90-26528

#### INTERACTIVE MULTI-BLOCK GRID GENERATION

DAVID J. AMDAHL (USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 579-588. refs

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A grid generation procedure combining interactive and batch grid generation programs has been developed to improve the flexibility and quality of generating multi-block grids around complex aircraft configurations. The interactive routine constructs the boundary domain for a multi-block grid by combining several common grid generation tools with a new approach for developing arbitrary, three-dimensional curves. A batch grid generation program generates the final three-dimensional grid from the boundary domain. This procedure generates multi-block grids for most aircraft geometries in a month or less. The time reduction to generate multi-block grids, the generality of applying this procedure, and the quality of the resultant flow solutions have proven this procedure as a capable tool for generating multi-block grids.

Author

**A90-26531\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

#### ADAPTIVE MESH GENERATION FOR VISCOUS FLOWS USING DELAUNAY TRIANGULATION

DIMITRI J. MAVRIPLIS (NASA, Langley Research Center; Institute for Computer Applications in Science and Engineering, Hampton, VA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 611-620. Previously announced in STAR as N88-29749. refs

Copyright

A method for generating an unstructured triangular mesh in two dimensions, suitable for computing high Reynolds number flows over arbitrary configurations is presented. The method is based on a Delaunay triangulation, which is performed in a locally stretched space, in order to obtain very high aspect ratio triangles in the boundary layer and the wake regions. It is shown how the method can be coupled with an unstructured Navier-Stokes solver to produce a solution adaptive mesh generation procedure for viscous flows.

Author

### A90-26533

#### THE GENERATION OF UNSTRUCTURED TRIANGULAR MESHES USING DELAUNAY TRIANGULATION

D. GRAHAM HOLMES and DEREK D. SNYDER (General Electric Co., Schenectady, NY) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 643-652. refs

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A numerical technique is developed analytically to generate unstructured two-dimensional triangular meshes for CFD simulations. The procedure is based on Delaunay triangulation, but is also capable of defining the interior points on arbitrary geometries. The determination of the boundary points and initial triangulation is explained; a three-phase rule-based approach to the creation of the interior points is outlined; and results are presented graphically for applications to (1) a generic hypersonic inlet with small leading-edge radius, (2) a set of two NACA 0012 airfoils, and (3) a swarm of NACA 0012 airfoils flying in formation.

T.K.

### A90-26534

#### 2-D AND 3-D UNSTRUCTURED MESH ADAPTION RELYING ON PHYSICAL ANALOGY

B. PALMERIO (Nice, Universite, France) and A. DERVIEUX (INRIA, Valbonne, France) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 653-663. refs

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A numerical procedure for the solution-oriented adaptation of an unstructured triangular mesh is developed analytically and demonstrated. The approach is based on the analogy to a system of interconnected springs (as proposed by Gnoffo, 1983), and mesh overlapping is avoided by application of a 'pseudopressure' penalty term. The global algorithm (previously described by Palmiero, 1987) facilitates the interaction between the flow solver and the mesh generator by integrating them in an arbitrary Lagrangian-Eulerian loop, typically requiring about 100 remeshings and 1000-2000 explicit flow iterations. Applications shown include (1) two-dimensional flow around a NACA 0012 airfoil at Mach 8 and angle of attack 20 deg, (2) three-dimensional flow past a thick wing, and (3) the three-dimensional interaction of two jets in a chamber.

T.K.

### A90-26536

#### GENERATION OF TETRAHEDRAL MESHES AROUND COMPLETE AIRCRAFT

TIMOTHY J. BAKER (Princeton University, NJ) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 675-685. Research supported by IBM Corp. refs

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A new  $O(N \log N)$  algorithm has been developed for generating a triangulation of point sets in three-dimensional space. The method exploits a generalized form of the Delaunay triangulation which can create unstructured meshes around aircraft shapes of arbitrary complexity.

Author

**A90-26537\*** Berkeley Research Association, Springfield, VA.

#### INTERACTIVE GENERATION OF UNSTRUCTURED GRIDS FOR THREE DIMENSIONAL PROBLEMS

RAINALD LOHNER (Berkeley Research Associates, Springfield, VA; U.S. Navy, Naval Research Laboratory, Washington, DC), PARESH PARIKH (Vigyan Research Associates, Hampton, VA), and CLYDE GUMBERT (NASA, Langley Research Center, Hampton, VA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 687-697. refs

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The present interactive grid-generation capability for

unstructured grids substantially bases itself on the performance available in the most advanced workstations, in order to obviate much of the input, error-checking, and output process burden associated with the generation of grids in three dimensions. The illustrative examples presented encompass the B-747 wing-fuselage configuration, a generic wing-fuselage-tail pathfinder configuration in a wind tunnel, and a generic train configuration in which surface data are not required to have very high accuracy, but many configurations must be analyzed rapidly. O.C.

**A90-26540**  
**ON THE COMBINATION OF STRUCTURED-UNSTRUCTURED MESHES**

N. P. WEATHERILL (Swansea, University College, Wales) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 729-739. Research supported by the Aircraft Research Association and Ministry of Defence Procurement Executive. refs  
 Copyright

This paper discusses techniques which can extend the flexibility and applicability of structured meshes. These gains are achieved by incorporating local regions of unstructured mesh within a globally structured mesh. By utilizing this approach, mesh enrichment to flowfield parameters can be performed, mesh quality can be improved and, in addition, a method is described which provides a means by which any structured mesh can be taken and generalized to include additional components of arbitrary geometrical complexity. The techniques will be illustrated in two dimensions with applications to the compressible flow over single and multi-element aerofoil configurations. Author

**A90-26542**  
**APPLICATION OF I-DEAS GRID GENERATOR FOR THREE-DIMENSIONAL TRANSONIC FLOW ANALYSIS**

R. K. ROUT (GE Aircraft Engines, Cincinnati, OH) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 761-773. refs  
 Copyright

Application of a general grid generator for the solution of transonic flow in a complex three-dimensional geometry is addressed in this paper. The adaptability of this mesh generation capability to solve fluid flow problems using modern computational techniques, such as multigridding and a block-structured algorithm based on parallel processing concepts, are also investigated. The application of this numerical grid generation technique to solve transonic flow in a three-dimensional nozzle with a transition duct using both finite volume and finite element numerical discretization techniques is described. Merits and limitations of this grid generation technique are evaluated through the use of this example problem. In order to evaluate the accuracy of the grid used for the transonic flow solution process, the results of the computation are compared with the available experimental data. Author

**A90-26543**  
**GRID GENERATION FOR AN AFT-FUSELAGE-MOUNTED NACELLE/PYLON CONFIGURATION**

N. D. HALSEY (Douglas Aircraft Co., Long Beach, CA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 775-784. Research sponsored by the McDonnell Douglas Independent Research and Development Program. refs  
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A method is presented for grid generation about an aft-fuselage-mounted nacelle/pylon configuration. The method makes extensive use of conformal mappings to transform the initially complicated geometry to a much simpler one - a flat-plate pylon between planar walls. Algebraic grid techniques are applied in the transformed space and the resulting points are subjected

to the mappings in reverse order to obtain the final grid in physical space. The transformations and algebraic techniques are described and a sample grid is shown. Author

**A90-26544**  
**ZONAL GRID GENERATION FOR FIGHTER AIRCRAFT**

ESSAM H. ATTA (Lockheed Aeronautical Systems Co., Burbank, CA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 785-794. refs  
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An efficient grid generation scheme has been developed for realistic aircraft configurations. The scheme is based on a zonal approach that simplifies the grid generation process and significantly reduces the time required to obtain suitable grids for complex geometries. In this scheme, the computational space around an aircraft configuration is divided into a number of non-overlapped blocks whose boundaries define the configuration surfaces and the limits of the computational space. H-type grids are generated independently in each region using a two-dimensional elliptic grid generation algorithm. The block grids are then smoothly patched together along common surfaces to ensure proper transition from one block to another. Examples of the generated grids for fighter aircraft demonstrate the effectiveness of the zonal grid generation scheme in modeling complex fighter configurations. Author

**A90-26545**  
**GEOMETRIC MODELLING OF COMPLEX AERODYNAMIC SURFACES AND THREE-DIMENSIONAL GRID GENERATION**

TH. SONAR and R. RADESPIEL (DLR, Institut fuer Entwurfsaerodynamik, Brunswick, Federal Republic of Germany) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 795-804. refs  
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Some techniques in grid generation are described for both geometric modeling and three-dimensional elliptic grid generation in the case of two very different configurations: (1) a wing-body combination with an H-0-0 mesh topology and a four-block structure in the computational domain and a reentry vehicle using a single block with a C-0 topology. (2) the emphasis is on new methods for elliptic grid generation. Author

**A90-26546\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

**INTERACTIVE GRID GENERATION FOR FIGHTER AIRCRAFT GEOMETRIES**

ROBERT E. SMITH and ERIC L. EVERTON (NASA, Langley Research Center, Hampton, VA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 805-814. refs  
 Copyright

An interactive procedure to construct grids about fighter aircraft configurations using a 'state-of-the-art' workstation is described. A multiple-block grid topology is used to minimize grid skewness. Grid points on the surface of a configuration are precomputed and stored on the faces of appropriate blocks. Grid points at intermediate and far field boundary surfaces are computed with analytical functions and stored on appropriate faces. Grid points in the interior of blocks are computed using transfinite interpolation with Lagrangian and exponential blending functions. Interactive software has been written for the IRIS 3030 graphics workstation to control the shape and spacing of grid points on intermediate and far field boundaries, and to control the interior interpolation. Author

**A90-26547\*** Old Dominion Univ., Norfolk, VA.  
**MULTIPLE-BLOCK GRID ADAPTION FOR AN AIRPLANE GEOMETRY**

JAMSHID SAMAREH ABOLHASSANI (Old Dominion University, Norfolk, VA) and ROBERT E. SMITH (NASA, Langley Research Center, Hampton, VA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 815-823. refs  
Copyright

Grid-adaption methods are developed with the capability of moving grid points in accordance with several variables for a three-dimensional multiple-block grid system. These methods are algebraic, and they are implemented for the computation of high-speed flow over an airplane configuration. Author

### A90-26552

#### GRID GENERATION AND ITS APPLICATION TO SEPARATED FLOWS

J. P. MARUSZEWSKI (United Technologies Corp., Pratt and Whitney Group, West Palm Beach, FL) and R. S. AMANO (Wisconsin, University, Milwaukee) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 885-894. refs  
Copyright

A method for the computation of recirculating flows on a nonorthogonal boundary-fitted coordinate system is presented. The algebraic grid generation technique is used to generate grids in an arbitrary shape of flow field. Computations are performed by using the set of governing equations transformed for use on a generalized curvilinear coordinate system. Turbulent computations use the k-epsilon model for most of the flow cases. Three pressure correction algorithms (SIMPLE, SIMPLEC, and PISO) are incorporated for use on a nonorthogonal grid. Comparisons are made on the basis of numerical stability and accuracy. It is found that the present method is efficient for computations of recirculating flows. Author

A90-26553\* National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

#### INTERACTIVE GRID GENERATION FOR TURBOMACHINERY FLOW FIELD SIMULATIONS

YUNG K. CHOO, CHARLES RENO (NASA, Lewis Research Center, Cleveland, OH), and PETER R. EISEMAN (NASA, Lewis Research Center, Cleveland, OH; Columbia University, New York) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 895-904. Previously announced in STAR as N89-11717. refs  
Copyright

The control point form of algebraic grid generation presented provides the means that are needed to generate well structured grids of turbomachinery flow simulations. It uses a sparse collection of control points distributed over the flow domain. The shape and position of coordinate curves can be adjusted from these control points while the grid conforms precisely to all boundaries. An interactive program called TURBO, which uses the control point form, is being developed. Basic features of the code are discussed and sample grids are presented. A finite volume LU implicit scheme is used to simulate flow in a turbine cascade on the grid generated by the program. Author

### A90-26554

#### C-GRID GENERATION FOR TURBOMACHINERY CASCADES

R. M. MOORE (U.S. Air Force Academy, Colorado Springs, CO) and J. D. HOFFMAN (Purdue University, West Lafayette, IN) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 905-914. refs  
Copyright

A Poisson-type elliptic partial differential equation grid generator with automatic control tailored to geometric requirements at individual boundaries is used to generate two-dimensional C-grids around turbomachinery cascade blades. Grid line intersection

angles and grid line spacing at the blade surface and inflow boundaries are controlled using a technique developed by Steger and Sorensen. Grid line slopes and grid line spacing at the periodic and grid cut (reentrant) boundaries are controlled using a newly developed technique. Discussion includes the development of the new source term calculation technique and an outline of the successive-over-relaxation grid generation procedure. Both grid generator results and flowfield prediction results for a turbine cascade are presented. Author

### A90-26556

#### NUMERICAL INTERACTIVE GRID GENERATION FOR 3D-FLOW CALCULATIONS

J. M. J. W. JACOBS, A. KASSIES, J. W. BOERSTOEL, F. BUIJSSEN (Nationaal Lucht- en Ruimtevaartlaboratorium, Amsterdam, Netherlands), and J. L. KUIJVENHOVEN (Fokker Aircraft, Amsterdam, Netherlands) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 925-943. Research supported by the Netherlands Instituut voor Vliegtuigontwikkeling en Ruimtevaart. refs  
Copyright

A method for the generation of three-dimensional block-structured grids is described. The grid generation process is decomposed into two major stages: (1) block decomposition of the flow domain, and (2) construction of a grid in each block. These two stages are decoupled to a large extent. Examples of grids are shown, together with flow solver results. With reference to these examples, some improvements and some future extensions of the present concepts are discussed. Author

### A90-26903\*#

Virginia Polytechnic Inst. and State Univ., Blacksburg.

#### BLADE-VORTEX INTERACTION EXPERIMENTS - VELOCITY AND VORTICITY FIELDS

MICHAEL C. WILDER, MATTHEW M. PESCE, DEMETRI P. TELIONIS (Virginia Polytechnic Institute and State University, Blacksburg), and DAVID R. POLING (Boeing Helicopters, Philadelphia, PA) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 11 p. Research supported by Boeing Vertol Co. refs  
(Contract NGT-50123)  
(AIAA PAPER 90-0030) Copyright

The blade-vortex interaction problem is studied experimentally with laser-Doppler velocimetry. Vortices are generated by pitching a NACA 0012 airfoil about its quarter chord and a target airfoil is mounted two chord lengths downstream of the vortex generator. LDV measurements are obtained in the neighborhood of the target airfoil's leading edge and ensemble-averaged velocity vector fields and vorticity contours are constructed. Vorticity fields are also constructed from velocity time records by assuming that, over short distances, the vorticity propagates with the local velocity. This assumption allows the blade-vortex interaction to be simulated from very few measurements. Author

### A90-26904#

#### INLET SWIRL EFFECTS ON DUMP COMBUSTOR FLOWS

R. S. NEJAD, R. S. BORAY, S. A. AHMED, and P. L. BUCKLEY (USAF, Aero Propulsion and Power Laboratory, Wright-Patterson AFB, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 11 p. Research supported by USAF. refs  
(AIAA PAPER 90-0035)

The results of an experimental investigation depicting the effects of swirl profile on confined flows in a sudden expansion coaxial dump combustor are presented. Three swirlers (free vortex, forced vortex, and constant angle) with the same nominal swirl number were designed and fabricated to study the effects of swirl type on the dump combustor flowfield. Imparting swirl to the inlet flow resulted in a considerable reduction of the corner recirculation length, a marked increase in turbulent mixing activity, and in one instance creation of a central recirculation zone. The present study highlighted the importance of the combustor inlet swirl profile and



showed that both swirl type and swirl strength can affect the flowfield significantly. The present data base is very well suited for CFD code development and validation. Author

**A90-26907\*#** Virginia Polytechnic Inst. and State Univ., Blacksburg.

#### THE HEMISPHERE-CYLINDER AT AN ANGLE OF ATTACK

D. P. TELIONIS (Virginia Polytechnic Institute and State University, Blacksburg), G. S. JONES (NASA, Langley Research Center, Hampton, VA), and N. HOANG AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 12 p. refs (Contract NAS1-19471; NGT-50144) (AIAA PAPER 90-0050) Copyright

The investigation of the flow over a cylinder with a hemispherical nose at an angle of attack is presented. Experiments were conducted in a 6 ft x 6 ft low-turbulence tunnel. The focus of this research is the separated region as well as the evaluation and testing of a new diagnostic tool, a fiber-optic laser-Doppler probe. A two-fold contribution is offered. On one hand, pressure distributions are provided along a fine grid over the body. On the other hand, a feasibility study is presented on the use of a fiber-optic LDV probe which can obtain data from inside the model. R.E.P.

**A90-26911\*#** Air Force Wright Research and Development Center, Wright-Patterson AFB, OH.

#### NUMERICAL SIMULATION OF AN F-16A AT ANGLE OF ATTACK

G. W. HUBAND, J. S. SHANG, and M. J. AFTOSMIS (USAF, Wright Research and Development Center, Wright-Patterson AFB, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 13 p. Research supported by NASA. refs (AIAA PAPER 90-0100) Copyright

The transonic flowfield around an F-16A fighter configuration at a moderate incidence angle is simulated by solving the Navier-Stokes equations on a single-block grid. The numerical solution matches experimental freestream conditions with a mach number of 0.85, 16 degrees angle of attack, and a characteristic Reynolds number of 12.75 million. MacCormack's explicit algorithm is used in conjunction with a local time step and consecutive mesh refinement procedure to accelerate numerical convergence. The Baldwin-Lomax algebraic model provides turbulent closure. Computed surface pressure distributions and the aircraft lift coefficient compare favorably with wind tunnel data. The drag coefficient in the simulation overpredicts the experimental value by 8 percent. Author

**A90-26933\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

#### UNSTEADY AERODYNAMIC CHARACTERISTICS OF A FIGHTER MODEL UNDERGOING LARGE-AMPLITUDE PITCHING MOTIONS AT HIGH ANGLES OF ATTACK

JAY M. BRANDON and GAUTAM H. SHAH (NASA, Langley Research Center, Hampton, VA) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 17 p. refs (AIAA PAPER 90-0309)

The effects of harmonic or constant-rate-ramp pitching motions (giving angles of attack from 0 to 75 deg) on the aerodynamic performance of a fighter-aircraft model with highly swept leading-edge extensions are investigated experimentally in the NASA Langley 12-ft low-speed wind tunnel. The model configuration and experimental setup are described, and the results of force and moment measurements and flow visualizations are presented graphically and discussed in detail. Large force overshoots and hysteresis are observed and attributed to lags in vortical-flow development and breakup. The motion variables have a strong influence on the persistence of dynamic effects, which are found to affect pitch-rate capability more than flight-path turning performance. T.K.

**A90-26936#**

#### PARALLEL COMPUTATION OF THREE-DIMENSIONAL TRANSONIC FLOW PROBLEMS WITH COMPLEX GEOMETRIES

A. ECER, J. T. SPYROPOULOS (Purdue University, Indianapolis, IN), and S. M. CHANG (IBM Numerically Intensive Computing Center, Kingston, NY) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. Research supported by the IBM Corp. refs

(Contract AF-AFOSR-80-0258)

(AIAA PAPER 90-0336) Copyright

Implementation of a block-structured solution scheme for solving for the transonic flow around an aircraft configuration on a parallel computer is presented. A computational grid is generated for an F-16 aircraft geometry employing 200 blocks. These blocks are processed on an IBM 3090 VF system with 4 processors in a multitasking arrangement. Numerical and performance results are presented. Author

**A90-26937#**

#### ANALYSIS OF UNSTEADY ROTOR-STATOR INTERACTIONS USING A VISCOUS EXPLICIT METHOD

SCOTT M. RICHARDSON (USAF, Aero Propulsion and Power Laboratory, Wright-Patterson AFB, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 13 p. refs (AIAA PAPER 90-0342)

An unsteady two-dimensional rotor-stator analysis has been developed and applied to the interaction between a rotor and upstream stator in a supersonic axial compressor. This analysis, which takes into account streamtube contraction effects, solves the Reynolds-averaged Navier-Stokes equations, using the Baldwin-Lomax eddy-viscosity model to account for turbulence effects. The equations are solved on an H-grid structure formulated to capture the rounded leading edges of modern compressor blades. A conservative interface condition, with a four-gridline overlap region, is used to maintain continuity of the damping functions. Results are presented for a 1:1 stator/rotor-blade ratio and clearly show the interaction of the rotor bow shock with the upstream stator wake. The global flowfield is shown to be dominated by the shedding of large vortices from separating flow on the upstream stator. The shedding frequency is approximately 12 times slower than the blade passing frequency. Author

**A90-26947#**

#### UNSTEADY HYPERSONIC VISCOUS FLOW IN IMPULSE FACILITIES

Y. BYUN, J. Y. LEE, J. D. ANDERSON, JR., and A. P. KOTHARI (Maryland, University, College Park) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 14 p. Research supported by the U.S. Navy. refs (AIAA PAPER 90-0421) Copyright

The hypersonic unsteady viscous flow over an aerodynamic model in a shock tunnel was simulated using a modified version of the TIMETVD code to solve the unsteady hypersonic viscous flow over a nozzle. Two shock waves of different families are identified numerically during the start-up process in the shock tunnel. As a result, for a Mach 6 designed nozzle, 4.58 m long, the flow establishment time around a circular cylinder is about 9.5 msec. V.L.

**A90-26956\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

#### OPERATIONAL CONSIDERATIONS FOR AERODYNAMIC TESTING OF LARGE-SCALE WING SECTIONS IN A SIMULATED NATURAL RAIN ENVIRONMENT

BRYAN A. CAMPBELL, GAUDY M. BEZOS, R. EARL DUNHAM, JR. (NASA, Langley Research Center, Hampton, VA), and W. EDWARD MELSON, JR. (NASA, Wallops Flight Center, Wallops Island, VA) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 11 p. refs (AIAA PAPER 90-0485)

One of the necessary areas of consideration for outdoor heavy rain testing is the effect of wind on both the simulated rain field and the quality and repeatability of the aerodynamic data. This paper discusses the data acquisition and subsequent reduction to nondimensional coefficients of lift and drag, with the appropriate correction for wind and rain field. Sample force data showing these



effects are presented, along with estimates for accuracy and repeatability. The capability to produce high-quality data for rain drop size distribution using photographic and computerized image processing techniques was developed. Sample photographs depicting rain drop size are shown. R.E.P.

**A90-26963\*#** Old Dominion Univ., Norfolk, VA.  
**THREE-DIMENSIONAL SHOCK-SHOCK INTERACTIONS ON THE SCRAMJET INLET**

D. J. SINGH, S. N. TIWARI (Old Dominion University, Norfolk, VA), and A. KUMAR (NASA, Langley Research Center, Hampton, VA) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 13 p. refs  
 (AIAA PAPER 90-0529) Copyright

The effects of shock impingement on the inlet of a scramjet engine are investigated numerically. The impinging shock is caused by the vehicle forebody. The interaction of this forebody shock with the inlet leading edge shock results in a very complex fully three-dimensional flowfield containing local regions of high pressure and intense heating. In the present investigation, this complex flowfield is calculated by solving the thin-layer Navier-Stokes equations using a finite-volume flux splitting technique due to van Leer. For zero or small sweep angles a Type IV interaction occurs while for moderate sweep of about 25 deg, a Type V interaction occurs. Both Type IV and Type V interactions are investigated. Author

**A90-26967\*#** Cincinnati Univ., OH.  
**A FLUX-SPLIT SOLUTION PROCEDURE FOR UNSTEADY INLET FLOWS**

H. S. PORDAL, P. K. KHOSLA, and S. G. RUBIN (Cincinnati, University, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. refs  
 (Contract NAG3-716; F49620-85-C-0027)  
 (AIAA PAPER 90-0585) Copyright

The unstart and restart of an axisymmetric inlet is investigated using a flux-split procedure applied to the Euler and Reduced Navier Stokes (RNS) equations. A time consistent direct sparse matrix solver is applied to compute the transient flow field both internal and external to the inlet. Time varying oblique and normal shocks are captured. The code is quite general and is applicable for subsonic, transonic and supersonic free streams. The current analysis is concerned with supersonic flight conditions. Author

**A90-26968#**  
**COMPARISON BETWEEN THIN LAYER AND FULL NAVIER-STOKES SIMULATIONS OVER A SUPERSONIC DELTA WING**

W. PHILLIP WEBSTER and JOSEPH S. SHANG (USAF, Wright Research and Development Center, Wright-Patterson AFB, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 10 p. refs  
 (AIAA PAPER 90-0589)

Steady flow fields describing the flow over a 75 deg swept delta wing at  $M 1.95$  and  $Re 4.48 \times 10^6$  to the 6th were simulated at angles of attack 20 and 30 deg using two computer codes. Comparisons were made between calculations using (1) the laminar and turbulent thin layer Navier-Stokes equations, and (2) laminar thin layer and Navier-Stokes equations. At an angle of attack of 20 deg, each equation set captures the essential structure of the flow and the differences between their results are minor. The Navier-Stokes equations were used to calculate the flow at 30 deg. A region of reversed flow along the surface near the trailing edge was observed. The vertical extent of this region was much smaller, but the upstream propagation extended much further than the previous thin layer simulation. Author

**A90-26969#**  
**THE FLOWFIELDS OF BURSTING VORTICES OVER MODERATELY SWEEPED DELTA WINGS**

JEROME T. KEGELMAN and FREDERICK W. ROOS (McDonnell Douglas Research Laboratories, Saint Louis, MO) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990.

14 p. refs  
 (Contract N62269-86-C-0284)  
 (AIAA PAPER 90-0599) Copyright

The off-body velocity and total-pressure-loss fields of the vortical flows over 60 and 70 deg delta wings were measured using three-component Laser Doppler and seven-hole-probe techniques. These measurements, conducted in a low-speed, low-turbulence research tunnel, are part of a broad database which included several measurement techniques. The range of angles of attack for the measurements included cases for which burst was observed over the wing. The leading-edge-vortex velocity field is shown to be approximately conical, with a maximum axial velocity that increases with increasing angle of attack. Burst causes a local increase in total-pressure loss and an expansion of total-pressure-loss cross-section. The maximum value of total-pressure loss decreases downstream of burst. Author

**A90-26970\*#** National Aeronautics and Space Administration, Lewis Research Center, Cleveland, OH.

**COMPARISON OF 3-D VISCOUS FLOW COMPUTATIONS OF MACH 5 INLET WITH EXPERIMENTAL DATA**

D. R. REDDY (NASA, Lewis Research Center; Sverdrup Technology, Inc., Cleveland, OH), T. J. BENSON, and L. J. WEIR (NASA, Lewis Research Center, Cleveland, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 14 p. refs  
 (Contract NAS3-25266)  
 (AIAA PAPER 90-0600) Copyright

The accuracy of the time-marching three-dimensional Navier-Stokes code PARC3D (Cooper et al., 1987) is evaluated using experimental data on a Mach 5 mixed-compression inlet configuration, obtained in the 10 x 10-ft working section of the supersonic wind tunnel at NASA Lewis. The basic principles of the PARC3D computations (in which the inlet and tunnel geometry and the bleed conditions are fully modeled) and the experimental setup are described, and the results are presented in extensive graphs and characterized in detail. PARC3D is shown to give reasonably accurate predictions of the bleed-zone elimination of low-energy vortical flow due to shock/boundary-layer interaction; various possible improvements are briefly considered. T.K.

**A90-26983#**  
**INSTABILITIES OF SUPERSONIC SHEAR FLOWS**

SAAD A. RAGAB and J. L. WU (Virginia Polytechnic Institute and State University, Blacksburg) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 20 p. refs  
 (Contract N00014-89-J-1544)  
 (AIAA PAPER 90-0712)

The interaction of a finite amplitude primary wave with its subharmonic in a compressible mixing layer is investigated using Floquet theory. Both temporal and spatial stability analyses are conducted. The effects of the Mach number and temperature ratio of the mean flow on the growth rate of the subharmonic are determined. Also the effect of the wavelength of the primary wave on the maximum growth rate of its subharmonic is determined. The results show that, for subsonic convective Mach numbers, the growth rate of the subharmonic can be increased by 50 percent due to the interaction with its primary wave. Author

**A90-26985#**  
**A NUMERICAL STUDY OF TRANSVERSE JETS INTO SUPERSONIC FLOWS AND INFLUENCE OF PRESSURE WAVES**

C. LI (Berkeley Research Associates, Springfield, VA) and K. KAILASANATH (U.S. Navy, Naval Research Laboratory, Washington, DC) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 11 p. Research supported by the U.S. Navy. refs  
 (AIAA PAPER 90-0733)

Numerical simulations of transverse jets into supersonic flows are conducted by solving the conservation equations of mass, momentum, energy, and species densities using a fourth order flux-corrected transport algorithm. These simulations show that the mixing between the jet and the main flow depends strongly

on the shocks and expansion waves induced by the transverse jet. Therefore, a systematic study of the influence of these pressure waves on mixing is also performed and effects of expansion and shock waves are analyzed. It is shown in the cases studied here that expansion waves play a favorable role when the value of the scalar product of density and pressure gradients is negative.

Author

**A90-27131**

**HYPersonic REACTIVE FLOW COMPUTATIONS**

J.-A. DESIDERI, N. GLINSKY, and E. HETTENA (INRIA, Valbonne, France) *Computers and Fluids* (ISSN 0045-7930), vol. 18, no. 2, 1990, p. 151-182. refs

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Finite-volume and finite-element solutions to the Euler equations are presented for the computation of hypersonic reactive flows around blunt bodies. The basic numerical method is explicit for the time integration. Robust spatial approximations are constructed from either first-order or MUSCL-type quasi-second-order upwind schemes in which the flux-vector splitting accounts for a mixture of 5 perfect gases (N<sub>2</sub>, O<sub>2</sub>, NO, N, and O) in the equation of state and for a local value of the parameter gamma, here defined as the ratio of enthalpy to internal energy. Equilibrium flow solutions are found by combining the basic method with a classical algebraic model, solved by Newton's method. Solutions to recently proposed nonequilibrium chemistry models are found by integrating forward in time additional transport equations. Treating the convection term explicitly, and the source term implicitly, the time step is only moderately reduced.

Author

**A90-27133\*** Analytical Services and Materials, Inc., Hampton, VA.

**VISCOUS COMPUTATIONS USING A DIRECT SOLVER**

V. VENKATKRISHNAN (Analytical Services and Materials, Inc., Hampton, VA) *Computers and Fluids* (ISSN 0045-7930), vol. 18, no. 2, 1990, p. 191-204. Research supported by NASA. refs

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Laminar viscous flows over airfoils are investigated analytically, applying the flux-difference splitting scheme of Roe (1986) to solve the thin-layer Navier-Stokes equations. Central-difference discretization is used for the viscous terms, and a fully implicit implementation is employed to minimize the Reynolds-number effect on convergence. Results for flows at freestream Mach number 0.5 and Reynolds number 5000 over NACA0012 airfoils at angles of attack 0 and 3 deg are presented graphically and discussed in detail. Good agreement with previous calculations is obtained, with accurate reproduction of essential features despite the use of coarser meshes.

T.K.

**A90-27303**

**CONDITIONS OF THE GENERATION OF AUTOOSCILLATIONS IN AERODYNAMIC CONTROL SURFACES IN NONSEPARATED SUBSONIC FLOW OF A GAS [USLOVIA VOZNIKOVENIIA AVTOKOLEBANII AERODINAMICHESKIKH POVERKHNOSTEI UPRAVLENIIA PRI BEZOTRYVNOI OBTEKANII OKOLOZVUKOVYI POTOKOM GAZA]**

A. V. SAFRONOV (Kievskoe Vysshee Voennoe Aviatsionnoe Inzhenernoe Uchilishche, Kiev, Ukrainian SSR) *Problemy Prochnosti* (ISSN 0556-171X), Feb. 1990, p. 50-55. In Russian. refs

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Conditions are examined which lead to the onset of autooscillations in aerodynamic control surfaces in subsonic gas flow in the presence of shock waves. It is shown that the highest excitation hinge moments, resulting from the interaction between oscillating control surfaces and shock waves, are observed when the shock waves occur near the trailing edge of the airfoil. Approximate analytical expressions are obtained which make it possible to estimate the maximum hinge moments of the control surfaces. A graphic interpretation of these relations is presented.

V.L.

**A90-27311\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**NAVIER-STOKES COMPUTATIONS USEFUL IN AIRCRAFT DESIGN**

TERRY L. HOLST (NASA, Ames Research Center, Moffett Field, CA) *AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990*. 15 p. refs  
(AIAA PAPER 90-1800) Copyright

Large scale Navier-Stokes computations about aircraft components as well as reasonably complete aircraft configurations are presented and discussed. Speed and memory requirements are described for various general problem classes, which in some cases are already being used in the industrial design environment. Recent computed results, with experimental comparisons when available, are included to highlight the presentation. Finally, prospects for the future are described and recommendations for areas of concentrated research are indicated. The future of Navier-Stokes computations is seen to be rapidly expanding across a broad front of applications, which includes the entire subsonic-to-hypersonic speed regime.

Author

**N90-16709** Illinois Univ., Urbana-Champaign.

**AN IMPROVEMENT OF CONVECTION FIDELITY IN EULER CALCULATIONS Ph.D. Thesis**

SHIAW SHINN CHU 1988 95 p

Avail: Univ. Microfilms Order No. DA8908655

A new solution procedure was developed to solve the Euler equations for steady, compressible, rotational, inviscid flows. The approach is aimed at achieving real inviscid solutions in Euler calculations by eliminating the numerical diffusion inherent in conventional approaches. In conventional approaches which solve for the time-dependent conservation equations, the numerical diffusion is either built-in through finite truncations or added externally for reasons of numerical stability. The resulting solutions are, therefore, not solutions to the Euler equations but to the pseudo Navier-Stokes equations with numerical viscosity instead of physical viscosity. That is, convective quantities in resulting Euler solutions are contaminated by numerical diffusion and false entropy production. This numerical diffusion is also responsible for the solution dependency on the grids used and the solution reliability of the Navier-Stokes solutions with physical viscosity terms. The present approach is based on splitting the character of the Euler equations into elliptic and convective quantities by using the Clebsch velocity decomposition. In the approach, the continuity equation is solved by a finite volume algorithm in the conservative form and then convective quantities are transported along streamlines without numerical diffusion. An efficient upwind difference scheme is developed to solve the convection equation for streamlines.

Dissert. Abstr.

**N90-16710\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

**NASA SUPERCRITICAL AIRFOILS: A MATRIX OF FAMILY-RELATED AIRFOILS**

CHARLES D. HARRIS Washington Mar. 1990 73 p  
(NASA-TP-2969; L-16625; NAS 1.60:2969) Avail: NTIS HC A04/MF A01 CSCL 01/1

The NASA supercritical airfoil development program is summarized in a chronological fashion. Some of the airfoil design guidelines are discussed, and coordinates of a matrix of family related supercritical airfoils ranging from thicknesses of 2 to 18 percent and over a design lift coefficient range from 0 to 1.0 are presented.

Author

**N90-16711** Catholic Univ. of America, Washington, DC.

**AN EXPERIMENTAL INVESTIGATION OF VISCOUS ASPECTS OF PROPELLER BLADE FLOW Ph.D. Thesis**

STUART DODGE JESSUP 1989 260 p

Avail: Univ. Microfilms Order No. DA8912977

An experimental investigation of the laminar/turbulent flow in the vicinity of a rotating propeller blade was conducted using laser Doppler velocimetry. Details of the flow were measured to assess the viscous features relative to classical potential theory.

Three-dimensional velocity component measurements were made of the propeller blade boundary layer and wake using laser Doppler velocimetry with a phase averaging technique to account for blade rotation. The propeller blade flow was characterized by streamwise and radial boundary layer profiles. Laminar boundary layers were initiated at the leading edge with transition to turbulence occurring at the mid-chord of the blade. The midspan streamwise boundary layer resembled typical two-dimensional behavior. The radial boundary layer exhibited large outward flow near the wall in regions of laminar flow which was reduced after transition. The outer blade boundary layer edge velocities along the blade were predicted by potential theory implying no significant viscous-inviscid interactions. Dissert. Abstr.

**N90-16712\*** Stanford Univ., CA. Dept. of Aeronautics and Astronautics.

### **CONTROLLED VORTICAL FLOW ON DELTA WINGS THROUGH UNSTEADY LEADING EDGE BLOWING**

K. T. LEE and LEONARD ROBERTS Jan. 1990 144 p  
(Contract NCC2-55)  
(NASA-CR-186267; NAS 1.26:186267; SU-JIAA-TR-97) Avail:  
NTIS HC A07/MF A01 CSCL 01/1

The vortical flow over a delta wing contributes an important part of the lift - the so called nonlinear lift. Controlling this vortical flow with its favorable influence would enhance aircraft maneuverability at high angle of attack. Several previous studies have shown that control of the vortical flow field is possible through the use of blowing jets. The present experimental research studies vortical flow control by applying a new blowing scheme to the rounded leading edge of a delta wing; this blowing scheme is called Tangential Leading Edge Blowing (TLEB). Vortical flow response both to steady blowing and to unsteady blowing is investigated. It is found that TLEB can redevelop stable, strong vortices even in the post-stall angle of attack regime. Analysis of the steady data shows that the effect of leading edge blowing can be interpreted as an effective change in angle of attack. The examination of the fundamental time scales for vortical flow re-organization after the application of blowing for different initial states of the flow field is studied. Different time scales for flow re-organization are shown to depend upon the effective angle of attack. A faster response time can be achieved at angles of attack beyond stall by a suitable choice of the initial blowing momentum strength. Consequently, TLEB shows the potential of controlling the vortical flow over a wide range of angles of attack; i.e., in both for pre-stall and post-stall conditions. Author

**N90-16720** ESDU International Ltd., London (England).  
**IN-PLANE FORCES AND MOMENTS ON INSTALLED  
INCLINED PROPELLERS AT LOW FORWARD SPEEDS**  
**Abstract Only**

Dec. 1989 22 p  
(ESDU-89047; ISBN-0-85679-721-9; ISSN-0141-397X) Avail:  
ESDU

ESDU 89047 gives simple semi-empirical methods for estimating the forces and moments on single or contra-rotating propellers inclined at angles up to 20 degrees with the local flow. The results are given graphically as derivatives with respect to the local flow angle, and that must be separately evaluated if forces and moments are required. The graphical data are plotted as functions of thrust coefficient (from 0 to maximum likely) and advance ratio from 0 to 3, for a range of values of solidity from 0.05 to 0.5. The data apply strictly to six-bladed propellers, but the results are found to be insensitive to the number of blades between 2 and 10. For cases where the solidity is unknown an approximate relationship is given to derive values from the total activity factor. Comparisons with test data extracted from the literature suggest the force derivatives are predicted to within 15 percent and moments to within 40 percent, but it is felt those are conservative assessments due to the test difficulties of measuring the small forces and moments. A detailed worked example illustrates the use of the data. ESDU

**N90-16721** ESDU International Ltd., London (England).  
**ESTIMATION OF SUBSONIC FAR-FIELD JET-MIXING NOISE  
FROM SINGLE-STREAM CIRCULAR NOZZLES Abstract Only**  
Dec. 1989 26 p Supersedes ESDU-74002  
(ESDU-89041; ISBN-0-85679-714-6; ISSN-0307-0115;  
ESDU-74002) Avail: ESDU

ESDU 89041 gives a graphical method for estimating overall and one-third octave band sound pressure levels as a function of observer distance and angle to the efflux plane, jet pipe diameter, and jet temperature and velocity. The method is derived by correlating experimental data from model tests in which all sources of noise other than that due to pure jet mixing have been eliminated. Atmospheric absorption and ground reflection effects are excluded. ESDU 85018 complements the method by providing a means for interpolating in or extrapolating any jet noise experimental data: it includes a database, which is that used here, and the user can replace or supplement that database as appropriate. ESDU

**N90-17539\*** West Virginia Univ., Morgantown. Dept. of Mechanical and Aerospace Engineering.  
**COMPUTATIONAL DESIGN OF LOW ASPECT RATIO  
WING-WINGLET CONFIGURATIONS FOR TRANSONIC  
WIND-TUNNEL TESTS Final Report, Jan. 1987 - May 1989**  
JOHN M. KUHLMAN and CHRISTOPHER K. BROWN Oct.  
1989 114 p  
(Contract NAG1-625)  
(NASA-CR-181939; NAS 1.26:181939) Avail: NTIS HC A06/MF  
A01 CSCL 01/1

Computational designs were performed for three different low aspect ratio wing planforms fitted with nonplanar winglets; one of the three configurations was selected to be constructed as a wind tunnel model for testing in the NASA LaRC 8-foot transonic pressure tunnel. A design point of  $M = 0.8$ ,  $C_{(sub L)}$  is approximate or  $= 0.3$  was selected, for wings of aspect ratio equal to 2.2, and leading edge sweep angles of 45 deg and 50 deg. Winglet length is 15 percent of the wing semispan, with a cant angle of 15 deg, and a leading edge sweep of 50 deg. Winglet total area equals 2.25 percent of the wing reference area. The design process and the predicted transonic performance are summarized for each configuration. In addition, a companion low-speed design study was conducted, using one of the transonic design wing-winglet planforms but with different camber and thickness distributions. A low-speed wind tunnel model was constructed to match this low-speed design geometry, and force coefficient data were obtained for the model at speeds of 100 to 150 ft/sec. Measured drag coefficient reductions were of the same order of magnitude as those predicted by numerical subsonic performance predictions. Author

**N90-17545** Aircraft Research Association Ltd., Bedford (England).

### **APPLICATION OF EXPERIMENTAL TECHNIQUES TO STORE RELEASE PROBLEMS**

MARYLYN E. WOOD In Nielsen Engineering and Research, Inc., Missile Aerodynamics: NEAR Conference on Missile Aerodynamics 45 p 1989  
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The various experimental techniques for the prediction of store release characteristics are reviewed and recent advances to the simulation capabilities are described. Examples of the application of these techniques to a wide range of store release problems are given and comparisons made with predictions by other computational ground-based methods and with flight. The value of developing an integrated method which combines wind tunnel data with a mathematical model to assess aircraft safety/store separation characteristics with a high level of confidence is strongly emphasized. Author

**N90-17548\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

### **A REVIEW OF HIGH-SPEED, CONVECTIVE, HEAT-TRANSFER COMPUTATION METHODS**

MICHAEL E. TAUBER In Nielsen Engineering and Research,

Inc., Missile Aerodynamics: NEAR Conference on Missile Aerodynamics 64 p 1989

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The objective is to provide useful engineering formulations and to instill a modest degree of physical understanding of the phenomena governing convective aerodynamic heating at high flight speeds. Some physical insight is not only essential to the application of the information presented here, but also to the effective use of computer codes which may be available to the reader. Given first is a discussion of cold-wall, laminar boundary layer heating. A brief presentation of the complex boundary layer transition phenomenon follows. Next, cold-wall turbulent boundary layer heating is discussed. This topic is followed by a brief coverage of separated flow-region and shock-interaction heating. A review of heat protection methods follows, including the influence of mass addition on laminar and turbulent boundary layers. Next is a discussion of finite-difference computer codes and a comparison of some results from these codes. An extensive list of references is also provided from sources such as the various AIAA journals and NASA reports which are available in the open literature.

Author

**N90-17549** Nielsen Engineering and Research, Inc., Mountain View, CA.

#### **PREDICTION METHODS FOR STORE SEPARATION**

MARNIX F. E. DILLENIUS and DAVID NIXON *In its* Missile Aerodynamics: NEAR Conference on Missile Aerodynamics 71 p 1989

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Theoretical approaches to the prediction of store separation characteristics are discussed. Historical developments of both the traditional engineering level and the much more recent CFD based methods are outlined. Various aspects of aircraft/store aerodynamic interference are pointed out. Early methods and methods presently in use and described in the open literature are discussed and examples given of their applications. The present engineering level methods include the NEAR programs and the AEDC direct method. The basic aspects of existing CFD technology are summarized, and specific applications to aircraft/store configurations are described. Given here are recommendations for future developments in predictive technology for store separation characteristics.

Author

**N90-17556** Old Dominion Univ., Norfolk, VA.

#### **LOW SPEED FLOWFIELD CHARACTERIZATION BY INFRARED MEASUREMENTS OF SURFACE TEMPERATURES Ph.D. Thesis**

EHUD GARTENBERG 1989 165 p

Avail: Univ. Microfilms Order No. DA8925387

An experimental program was aimed at identifying areas in low speed aerodynamic research where infrared imaging systems can make significant contributions. Implementing a new technique, a long electrically heated wire was placed across a laminar jet. By measuring the temperature distribution along the wire with the IR imaging camera, the flow behavior was identified. Furthermore, using Nusselt number correlations, the velocity distribution could be deduced. The same approach was used to survey wakes behind cylinders in a wind-tunnel. This method is suited to investigate flows with position dependent velocities, e.g., boundary layers, confined flows, jets, wakes, and shear layers. It was found that the IR imaging camera cannot accurately track high gradient temperature fields. A correction procedure was devised to account for this limitation. Other wind-tunnel experiments include tracking the development of the laminar boundary layer over a warmed flat plate by measuring the chordwise temperature distribution. This technique was applied also to the flow downstream from a rearward facing step. Finally, the IR imaging system was used to study boundary layer behavior over an airfoil at angles of attack from zero up to separation. The results were confirmed with tufts observable both visually and with the IR imaging camera.

Dissert. Abstr.

**N90-17557** Pennsylvania State Univ., University Park.

#### **SKIN FRICTION MEASUREMENTS BY LASER INTERFEROMETRY IN SUPERSONIC FLOWS Ph.D. Thesis**

KWANG-SOO KIM 1989 229 p

Avail: Univ. Microfilms Order No. DA8922069

The measurement of skin friction in complex compressible flows is difficult, and very few reliable techniques are available. A recent development, the Laser Interferometer Skin Friction (LISF) meter, is shown to be useful for this purpose. This technique interferometrically measures the time rate of thinning of an oil film applied to an aerodynamic surface. Under proper conditions the wall shear stress may thus be found directly, without reference to flow properties. For the calibration of the LISF meter, the technique is initially applied to supersonic flat plate turbulent boundary layers at nominal Mach numbers of 2.5, 3.0, 3.5, and 4.0. Its accuracy and repeatability are assessed, and conditions required for its successful application are described. The LISF technique is also applied to obtain reliable skin friction data in 3-D swept shock wave/turbulent boundary layer interactions. Two sets of experiments are performed at a nominal Mach number of 3.0, and at fin shock-generator angles of 10 and 16 degrees. The results show that such measurements are practical in high speed interacting flows, and that a repeatability of plus or minus 6 percent or better is obtained. Further, useful information is gained on the behavior of the wall shear stress beneath swept shock wave/boundary layer interactions. Finally, these data are used in a computational fluid dynamics (CFD) code validation exercise. Dissert. Abstr.

**N90-17558\*** Notre Dame Univ., IN. Dept. of Aerospace and Mechanical Engineering.

#### **SURFACE PRESSURE DISTRIBUTIONS ON A DELTA WING UNDERGOING LARGE AMPLITUDE PITCHING OSCILLATIONS M.S. Thesis**

SCOTT A. THOMPSON Dec. 1989 171 p

(Contract NAG1-727)

(NASA-CR-186326; NAS 1.26:186326) Avail: NTIS HC A08/MF A01 CSCL 01/1

Wind tunnel experiments were performed on a 70 deg sweep delta wing to determine the effect of a sinusoidal pitching motion on the pressure field on the suction side of the wing. Twelve pressure taps were placed from 35 to 90 percent of the chord, at 60 percent of the local semi-span. Pressure coefficients were measured as a function of Reynolds number and pitch rate. The pressure coefficient was seen to vary at approximately the same frequency as the pitching frequency. The relative pressure variation at each chord location was comparable for each case. The average pressure distribution through each periodic motion was near the static distribution for the average angle of attack. Upon comparing the upstroke and downstroke pressures for a specific angle of attack, the downstroke pressures were slightly larger. Vortex breakdown was seen to have the most significant effect at the 40 to 45 percent chord location, where a decrease in pressure was apparent.

Author

**N90-17560\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

#### **SUPERSONIC AERODYNAMIC CHARACTERISTICS OF A PROPOSED ASSURED CREW RETURN CAPABILITY (ACRC) LIFTING-BODY CONFIGURATION**

GEORGE M. WARE Nov. 1989 75 p

(NASA-TM-4136; L-16627; NAS 1.15:4136) Avail: NTIS HC A04/MF A01 CSCL 01/1

An investigation was conducted in the Langley Unitary Plan Wind Tunnel at Mach numbers from 1.6 to 4.5. The model had a low-aspect-ratio body with a flat undersurface. A center fin and two outboard fins were mounted on the aft portion of the upper body. The outboard fins were rolled outboard 40 deg from the vertical. Elevon surfaces made up the trailing edges of the outboard fins, and body flaps were located on the upper and lower aft fuselage. The center fin pivoted about its midchord for yaw control. The model was longitudinally stable about the design center-of-gravity position at 54 percent of the body length. The configuration with undeflected longitudinal controls trimmed near

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0 deg angle of attack at Mach numbers from 1.6 to 3.0 where lift and lift-drag ratio were negative. Longitudinal trim was near the maximum lift-drag ratio (1.4) at Mach 4.5. The model was directionally stable over Mach number range except at angles of attack around 4 deg at  $M = 2.5$ . Pitch control deflection of more than -10 deg with either elevons or body flaps is needed to trim the model to angles of attack at which lift becomes positive. With increased control deflection, the lifting-body configuration should perform the assured crew return mission through the supersonic speed range. Author

**N90-17561\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

### **ENGINE INLET DISTORTION IN A 9.2 PERCENT SCALE VECTORED THRUST STOVL MODEL IN GROUND EFFECT**

ALBERT L. JOHNS, GEORGE NEINER, J. D. FLOOD, K. C. AMUEDO, and T. W. STROCK (McDonnell-Douglas Corp., Saint Louis, MO.) 1989 24 p Presented at the 25th Joint Propulsion Conference, Monterey, CA, 10-12 Jul. 1989; cosponsored by AIAA, ASME, SAE, and ASEE (NASA-TM-102358; E-5072; NAS 1.15:102358; AIAA-89-2910) Avail: NTIS HC A03/MF A01 CSCL 01/1

Advanced Short Takeoff/Vertical Landing (STOVL) aircraft which can operate from remote locations, damaged runways, and small air capable ships are being pursued for deployment around the turn of the century. To achieve this goal, NASA Lewis Research Center, McDonnell Douglas Aircraft, and DARPA defined a cooperative program for testing in the NASA Lewis 9- by 15-foot low speed wind tunnel (LSWT) to establish a database for hot gas ingestion, one of the technologies critical to STOVL. Results are presented which show the engine inlet distortions (both temperature and pressure) in a 9.2 percent scale vectored thrust STOVL model in ground effects. Results are shown for the forward nozzle splay angles of 0 degrees, -6 degrees, and 18 degrees. The model support system had 4 degrees of freedom, heated high pressure air for nozzle flow, and a suction system exhaust for inlet flow. The headwind (freestream) velocity was varied from 8 to 23 knots. Author

**N90-17562\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

### **NUMERICAL SOLUTIONS OF THE LINEARIZED EULER EQUATIONS FOR UNSTEADY VORTICAL FLOWS AROUND LIFTING AIRFOILS**

JAMES R. SCOTT and HAFIZ M. ATASSI (Notre Dame Univ., IN.) 1990 21 p Presented at the 28th Aerospace Sciences Meeting, 8-11 Jan. 1990; sponsored by AIAA (NASA-TM-102466; E-5137; NAS 1.15:102466; AIAA-90-0694) Avail: NTIS HC A03/MF A01 CSCL 01/1

A linearized unsteady aerodynamic analysis is presented for unsteady, subsonic vortical flows around lifting airfoils. The analysis fully accounts for the distortion effects of the nonuniform mean flow on the imposed vortical disturbances. A frequency domain numerical scheme which implements this linearized approach is described, and numerical results are presented for a large variety of flow configurations. The results demonstrate the effects of airfoil thickness, angle of attack, camber, and Mach number on the unsteady lift and moment of airfoils subjected to periodic vortical gusts. The results show that mean flow distortion can have a very strong effect on the airfoil unsteady response, and that the effect depends strongly upon the reduced frequency, Mach number, and gust wave numbers. Author

**N90-17564** Cincinnati Univ., OH.

### **ANALYSIS AND NUMERICAL SOLUTION OF FLOW OVER AIRFOIL WITH CONTROL FLAP Ph.D. Thesis**

CHENG-WEI LIAO 1989 220 p  
Avail: Univ. Microfilms Order No. DA9003254

The purpose of this research is to achieve and analyze numerical solutions and aerodynamic properties of the NACA0012 airfoil with and without control flap, at different angles of attack. A numerical grid-generation based on conformal mapping is employed to develop an orthogonal surface-oriented coordinate

system for the complex geometry of the air foil with general orientation of the control flap. The Navier-Stokes equations are solved by using the ARC2D code developed by the NASA Ames Research Center. The code solves the thin-layer Navier-Stokes equations by implicit finite-difference scheme using time linearization, approximate factorization and diagonalization of the coefficient of matrix. For the basic NACA0012 airfoil, comparison of the numerical solutions with experimental data shows that the numerical predictions are quite good. For the airfoil with control flap, the numerical solutions obtained are persistently unsteady. Mach contour and pressure contour are used to demonstrate the flow structure. The capability developed for generating grid and determining the flow for airfoil with a control flap provides the foundations for innovative airfoil-flap design and flow control. Dissert. Abstr.

**N90-17566\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **OPPORTUNITIES FOR IMPROVED UNDERSTANDING OF SUPersonic AND HYPERSONIC FLOWS**

ROBERT A. JONES /in AGARD, Special Course on Three-Dimensional Supersonic/Hypersonic Flows Including Separation 44 p Jan. 1990

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This overview describes some of the diverse applications which are foreseen in the supersonic and hypersonic regime, and points out both the need and the opportunity for improved understanding of the subject. New facilities and experimental test techniques combined with computational fluid dynamics methods are described to illustrate challenging flows over supersonic wings, separated free-shear mixing layers, and in scramjet-airframe integration. Author

**N90-17569#** Calspan-Buffalo Univ. Research Center, NY.

### **SHOCK-SHOCK BOUNDARY LAYER INTERACTIONS**

MICHAEL S. HOLDEN /in AGARD, Special Course on Three-Dimensional Supersonic/Hypersonic Flows Including Separation 134 p Jan. 1990

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A study is presented of the aerothermal characteristics of shock/shock boundary layer interactions generated by single and multiple shocks. A review is presented of experimental studies which were conducted over the Mach number range from Mach 2 to 19 in the continuous and short duration test facility. The results of recent experimental studies in which detailed measurements of the distribution of heat transfer and pressure were made for Types 3 and 4 interactions in laminar flows at Mach 6 and 19 are discussed in detail. In these studies measurements at Mach 6 to 19 indicated that the severity of the interaction increased with transition and increasing Mach number, as suggested from simple models. Some Type 4 interactions where maximum heating occurs can also be unstable and, therefore, may be difficult to predict with accuracy. The studies of multiple shock interaction demonstrated that the largest heat loads are generated on the cylinder if the shocks coalesce before they are incident on the cylinder. While the flow fields and aerothermal loads generated by multiple shock impingement provide test cases for code prediction, the peak heating loads are significantly less than for a single shock of the same strength. Because of the low Reynolds numbers at which transition occurs in the free shear layers developed from either single or multiple shock/shock interactions, coupled with the occurrence of flow instabilities for Type 4 interactions, it will be difficult to accurately predict the maximum heating in such flows over a large and important part of the flight regime. However, the major feature of the flow field and pressure distributions were predicted with good accuracy with finite difference and finite element schemes for the solutions of the Navier-Stokes equations. Author

**N90-17571#** Cranfield Inst. of Tech., Bedford (England). Coll. of Aeronautics.

**GLANCING SHOCK-BOUNDARY LAYER INTERACTIONS**

JOHN L. STOLLERY In AGARD, Special Course on Three-Dimensional Supersonic/Hypersonic Flows Including Separation 30 p Jan. 1990

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There is no universally agreed definition of glancing interaction but it is usually taken to include those situations where the shock wave generated by one body cuts across the boundary layer growing over another and the intersection line is swept. Such flows are essentially three dimensional and are a sub-set of the many swept interactions. In the simplest glancing interactions the only shock wave of interest is that formed by the shock wave generator. Similarly the only boundary layer of interest is the one affected by shock impingement. The boundary layer development on the shock generator and any shock from the surface supporting the boundary layer are secondary in importance. Thus the more complex corner flows and shock-shock interactions are played in categories of their own and enjoy individual treatment. Just four of the many geometries available will be discussed. These four cover the effects of sweep and bluntness on a fin mounted at right angles to a flat plate. Discussed are sharp unswept fins, sharp swept fins, blunt unswept fins, and blunt swept fins. These models can easily be tested experimentally with the fin mount on a sharp leading edge flat plate or mounted directly from the wall of a wind tunnel test section. However, even with these relatively simple geometries it would be foolish to ignore the mutual interference between the two surfaces. In particular the bow shock generated by a blunt fin will often cause boundary layer separation ahead of the fin root. This in turn generates an oblique shock which interacts with the bow shock so producing an example of the shock-shock interactions treated in detail elsewhere in this course. Similarly, a turbulent boundary layer at the base of a swept blunt fin may trigger leading-edge contamination along the attachment line with consequent increases in heat transfer rate. Hence wherever possible the flow pattern over both the plate and fin surfaces will be investigated. Author

**N90-17574#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**EFFECT OF RIBBLETS ON FLOW SEPARATION FROM A CYLINDER AND AN AIRFOIL IN SUBSONIC FLOW M.S. Thesis**

TIMOTHY D. WIECK Dec. 1989 86 p  
(AD-A216197; AFIT/GAE/ENY/89D-40) Avail: NTIS HC A05/MF A01 CSCL 20/4

This thesis investigated the effect of riblets on flow separation from a cylinder and an airfoil in subsonic flow. Riblets have been used successfully to reduce viscous drag on a flat plate and significantly delay flow separation in a two-dimensional, straight-walled, subsonic diffuser. The investigation indicated that for a 2-D cylinder model, the separation point could be delayed as much as 5.5 percent by applying riblets to the model surface. Minor delays in separation were also achieved by applying riblets to a 2-D airfoil model at 8 and 12 deg angle of attack. Applying riblets to the cylinder and airfoil models consistently altered the pressure distribution compared to the same models without riblets. In comparing the cylinder and airfoil results with those of the subsonic diffuser, it appears that riblets are most effective in delaying flow separation in relatively weak adverse pressure gradients. GRA

**N90-17575#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**HYPersonic NOZZLE/AFTERBODY PERFORMANCE AT LOW MACH NUMBERS M.S. Thesis**

R. BRUCE COCHRAN Dec. 1989 197 p  
(AD-A216223; AFIT/GAE/AA/89J-2) Avail: NTIS HC A09/MF A01 CSCL 21/1

The propulsion system for an airbreathing vehicle that operates over a wide Mach number range, subsonic to hypersonic speeds,

must be highly integrated into the airframe. The most promising design concept for hypersonic speeds is an airframe-integrated supersonic combustion ramjet (scramjet) which blends aircraft forebody and afterbody functions in combination with the engine (combustors) modules. The low speed performance of a generic 2-D hypersonic nozzle/afterbody configuration was studied experimentally. Wind tunnel tests were conducted at simulated flight Mach numbers of 0.6, 0.8, 1.9, and 3.0, in a Two-Foot Trisonic Gasdynamics Facility (TGF). Parametrics included four cowl configurations and simulated propulsion variations with high pressure, cold (ambient temperature) air. The exhaust flow characteristics, the pressure distributions, pressure coefficients, and pressure drags, were determined. The nozzle/afterbody exhaust flows were overexpanded for all of the configurations and conditions, and produced a pressure drag (thrust loss). The exhaust flow characteristics of the subsonic and supersonic flight Mach numbers were different. The subsonic condition resulted in higher pressure drag levels than for the supersonic conditions. The subsonic pressure drag levels increased with increasing nozzle pressure ratios (NPR), while for the supersonic conditions, the pressure drag levels were nearly constant or decreased with increasing NPR. GRA

**N90-17576#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**A COMPUTATIONAL MODEL FOR THICKENING BOUNDARY LAYERS WITH MASS ADDITION FOR HYPERSONIC ENGINE INLET TESTING M.S. Thesis**

ROBERT DOUGLAS CLAUSEN Dec. 1989 87 p  
(AD-A216246; AFIT/GAE/ENY/89D-04) Avail: NTIS HC A05/MF A01 CSCL 21/1

The United States Air Force is currently pursuing a national program to develop the technology necessary to build a single staged aircraft capable of flying from conventional runways into orbit. This vehicle, the National Aerospace Plane (NASP), will use airbreathing propulsion to accelerate through hypersonic speeds to orbital velocities. In order to achieve the aerodynamic and propulsive efficiencies necessary to accomplish this goal, the vehicle forebody must be used as a precompression surface for the engine flowpath. This results in a thick boundary layer which must be bled-off or ingested by the engine. A computational model for thickening boundary layers with mass addition is developed. The phenomena of uniform injection into a two-dimensional supersonic stream and subsequent boundary layer growth downstream is discussed. Analysis of the injection region provides the thickness of the boundary layer just aft of injection. An injection region velocity profile is then used to approximate the boundary layer profile just aft of injection and is input into a finite-difference boundary layer code. Downstream profiles and thicknesses are calculated and compared to experimental results. The computational model developed here provides a tool for the design of a boundary layer generation system for hypersonic engine inlet testing. This mass addition system is needed to simulate the boundary layer developed on the forebody of hypersonic vehicles. GRA

**N90-17577#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**A WIND TUNNEL STUDY OF A STING-MOUNTED CIRCULATION CONTROL WING M.S. Thesis**

JOHN W. TRAINOR Dec. 1989 86 p  
(AD-A216248; AFIT/GAE/ENY/89D-38) Avail: NTIS HC A05/MF A01 CSCL 01/1

This wind tunnel study investigated the feasibility of testing a sting mounted circulation control wing. A 20 percent, 8.5 percent cambered rectangular wing was designed, built, and tested in the AFIT 5-ft wind tunnel. Lift, drag, equivalent drag, and pitching moment coefficients were obtained at Reynolds numbers of 600,000 and 900,000. The force and moment results achieved indicate supercirculation was not present. Flow visualization with nylon tufts displayed extreme flow disruption at the trailing edge, due to free-stream impingement on both the sting and blowing air supply hoses. The available blowing air supply was not strong



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enough to produce a jet flow with the momentum needed to overcome this disruption. Wing model design changes were recommended to alleviate this problem. GRA

**N90-17578#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

### **EXPERIMENTAL INVESTIGATION TO SUPPRESS FLOW-INDUCED PRESSURE OSCILLATIONS IN OPEN CAVITIES M.S. Thesis**

ROBERT L. SARNO Dec. 1989 119 p  
(AD-A216285; AFIT/GAE/ENY/89D-32) Avail: NTIS HC A06/MF A01 CSCL 01/1

High speed tangential flow over open cavities (e.g., aircraft weapon bays) can invoke large pressure oscillations within the cavity. These large oscillations can damage the cavity structure as well as items placed within the cavity. The purpose of this experimental study was to determine the effectiveness of suppressing pressure oscillations by manipulating the shear layer over a two-dimensional cavity with a length-to-depth ratio of two. Two methods, a frequency controllable control surface (fence) and pulsating secondary airflow at the cavity leading edge, were used to manipulate the shear layer. The suppression effectiveness of the fence utilized in both passive and active modes (zero to 120 Hz) was evaluated at six airflow Mach numbers (0.62, 0.76, 0.90, 1.07, 1.28, 1.53). The effectiveness of pulsating secondary airflow was evaluated at one airflow Mach number (1.28) and two flow injection angles (parallel and 45 degrees to the flow) at frequencies ranging from zero to 80 Hz. The effect of steady flow injection was also evaluated at mass flow rates per unit width ranging from 0.323 to 1.27 (lbm/sec/ft). Pressure recordings from within the cavity were made for each test. The effectiveness of a pulsating fence in suppressing the peak mode pressure oscillations proved to be less than that achievable with the fence static. The pulsed secondary flow injection technique was most effective when pulsed at a 45 degree angle to the external flow. GRA

**N90-17579#** Georgia Inst. of Tech., Atlanta. School of Aerospace Engineering.

### **NUMERICAL SIMULATION OF SUPERSONIC FREE SHEAR LAYERS Semiannual Progress Report, 1 Jun. - 30 Nov. 1989**

L. N. SANKAR and I. TUNCER Dec. 1989 19 p  
(Contract N00014-89-J-1319)  
(AD-A216289) Avail: NTIS HC A02/MF A01 CSCL 20/4

The 3-D supersonic shear layers can asymptotically approach a growth rate equal to 30 percent of that of subsonic shear layers. In an attempt to explain this phenomena, a series of analytical, experimental and computational studies were recently carried out. Many of these studies focused on 2-D supersonic shear layers. In these studies, and in particular, studies based on stability analysis to 2-D supersonic shear layers, it was found that the shear layer growth rate approaches zero (and not the 30 percent observed originally) as the connective Mach number of the shear layer increased from subsonic and supersonic. Several theories have been proposed to explain the discrepancies between 2-D analysis and 3-D observations. The objective of this research was to study the stability and growth characteristics of 3-D free shear layers through a numerical solution of the 3-D unsteady, compressible Navier-Stokes equations. A general solution procedure was constructed that may be used to study the temporal and spatial growth of 2-D and 3-D waves, to study the effects of random initial disturbances on the shear layer growth and to study the effects of wall on the shear layer growth. This procedure thus complements the well developed techniques of linear stability analysis, and allows one to study additional non-linear phenomena such as saturation of modes, vortex pairing phenomena etc. GRA

**N90-17580#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

### **AN ITERATIVE SOLUTION TO AEROELASTIC EFFECTS IN POTENTIAL FLOW M.S. Thesis**

RAYMOND C. MAPLE Dec. 1989 101 p

(AD-A216291; AFIT/GAE/ENY/89D-22) Avail: NTIS HC A06/MF A01 CSCL 01/1

The purpose of the study was to develop a method of incorporating static aeroelastic effects into a vortex paneling aerodynamic solution. The study had two basic objectives: Devise a solution technique and Implement the technique and analyze several test cases. An iterative solution is developed which uses MSC/NASTRAN to perform structural analysis, and a 3-D vortex paneling method to perform aerodynamic analysis. The theory behind the method and details of the implementation are presented. The method is tested for three bodies: a unit aspect ratio rectangular flat plate wing, a rectangular flat plate wing with aspect ratio 6, and a hollow sphere. Results of these tests are used to evaluate both the general performance of the implementation, and the performance for the specific test. The results indicate that the iterative solution method is robust and could potentially be used for solving a variety of aeroelastic problems. Recommendations for further development, evaluation, and use are made. GRA

**N90-17650\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **HIGH REYNOLDS NUMBER TESTS OF THE CAST-10-2/DOA 2 TRANSONIC AIRFOIL AT AMBIENT AND CRYOGENIC TEMPERATURE CONDITIONS**

E. STANEWSKY, F. DEMURIE (Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Goettingen, Germany, F.R.), EDWARD J. RAY, and C. B. JOHNSON *In its* CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 47-60 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

The transonic airfoil CAST 10-2/DOA 2 was investigated in several major transonic wind tunnels at Reynolds numbers ranging from  $Re = 1.3 \times 10^6$  to  $45 \times 10^6$  at ambient and cryogenic temperature conditions. The main objective was to study the degree and extent of the effects of Reynolds number on both the airfoil aerodynamic characteristics and the interference effects of various model-wind-tunnel systems. The initial analysis of the CAST 10-2 airfoil results revealed appreciable real Reynolds number effects on this airfoil and showed that wall interference can be significantly affected by changes in Reynolds number thus appearing as true Reynolds number effects. Author

**N90-17651\*#** Institut fuer Theoretische Stroemungsmechanik, Goettingen (Germany, F.R.).

### **SOME NAVIER-STOKES CALCULATIONS FOR THE CAST-10 AIRFOIL**

D. SCHWAMBORN *In* NASA, Langley Research Center, CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 61-81 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

Results of the simulation of the viscous flow past the CAST-10 airfoil were shown for different flow conditions. Since the experiments provide only surface pressures and force coefficients, the comparison to the numerical results relies on these. Good agreement of these results is found for the lower Mach number cases except for the shock position. As numerical experiments indicate, this seems to be due to the turbulent shock boundary layer interaction which is not correctly modelled by the algebraic turbulence model employed. For the lower Mach number case the influence of the transition location was investigated, too. Changing the transition location at the lower surface has much more influence on the pressure distribution than changing it on the upper side. For the higher Mach number case the double shock structure found in the experiment for the lower Reynolds numbers was not reproduced by the numerical solutions. The reason for this is unknown though it may be due to the turbulence modelling. For the higher Reynolds number a better resolution of the boundary layer is needed in the computation in order to recover the experimental pressure plateau; but then the shock position is still found downstream of the experimental one. K.C.D.

**N90-17652\*#** Centre d'Etudes et de Recherches, Toulouse (France).

**MAIN RESULTS OF CAST-10 AIRFOIL TESTED IN T2 CRYOGENIC WIND TUNNEL**

A. BLANCHARD, A. SERAUDIE, and J. F. BREIL *In* NASA, Langley Research Center, CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 83-98 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

The aim of this cooperative NASA/DFVLR/ONERA project was to examine the performance of the CAST-10 airfoil in the T2 cryogenic wind tunnel. Tests included general characteristics of the CAST-10 airfoil and fundamental studies on Reynold number effects. Good T2 cryogenic operation was observed. Improvements should be done for moisture elimination and for side wall boundary layer effects. K.C.D.

**N90-17653\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

**AN EXPERIMENTAL AWTS PROCESS AND COMPARISONS OF ONERA T2 AND 0.3-M TCT AWTS DATA FOR THE ONERA CAST-10 AEROFOIL**

STEPHEN WOLF (Vigyan Research Associates, Inc., Hampton, VA.) and RENALDO JENKINS *In its* CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 137-153 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

An experimental Adaptive Wall Test Section (AWTS) process is described. Comparisons of the ONERA T2 and the 0.3-m TCT (transonic cryogenic tunnel) AWTS data for the ONERA CAST-10 airfoil are presented. Most of the 0.3-m TCT data is new and preliminary and no sidewall boundary layer control is involved. No conclusions are given. K.C.D.

**N90-17654\*#** National Aeronautical Establishment, Ottawa (Ontario).

**INVESTIGATION OF CAST-10-2/DOA 2 AIRFOIL IN NAE HIGH REYNOLDS NUMBER TWO-DIMENSIONAL TEST FACILITY**

Y. Y. CHAN *In* NASA, Langley Research Center, CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 155-174 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

A common airfoil model with the CAST 10-2/DOA-2 profile and 228 mm (9 inches) chord length was tested. The tests performed in NAE covered the Mach numbers from 0.3 to 0.8 and Reynolds numbers from 10 to 30 million. The model was tested with transition free and with transition fixed at 5 percent chord for both the upper and the lower surfaces. The data obtained were analyzed for the effects of Reynolds number, transition fixing and Mach number. The role of the boundary layer on the displacement effect, the interaction with the shock wave and the trailing edge separation are examined. The results are summarized as follows: (1) the airfoil performance depends strongly on Reynolds number and transition fixing; (2) with transition fixed, the aerodynamic quantities such as lift, pitching moment and drag show a monotonic variation with Reynolds number; (3) with transition free, the aerodynamic quantities vary less regularly with Reynolds number and a slight parametric dependency is shown. The weak dependency is due to the compensatory effect of the forward shift of the transition position and the thinning of the turbulent boundary layer as Reynolds number increases; (4) the shock Mach number and the shock position are weakly dependent on Reynolds number; and (5) the long extent of the laminar boundary layer at transonic speeds reduces the drag appreciably at low Reynolds numbers. The drag bucket around the design Mach number can be observed below Reynolds number 15 million. K.C.D.

**N90-17657\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

**EXPERIENCE WITH SOME REPEAT TESTS ON THE 9 INCH CHORD CAST-10-2/DOA 2 AIRFOIL MODEL IN THE LANGLEY 0.3-M TCT ADAPTIVE WALL TEST SECTION**

A. V. MURTHY (Vigyan Research Associates, Inc., Hampton, VA.) and EDWARD J. RAY *In its* CAST-10-2/DOA 2 Airfoil Studies

Workshop Results p 213-231 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

A co-operative testing program is in progress between the Langley Research Center (NASA) and the National Aeronautical Establishment (NAE, Canada) to validate two different techniques of airfoil testing at transonic speeds. The procedure employed is to test the same airfoil model in the NAE two-dimensional tunnel and the Langley 0.3-m Transonic Cryogenic Tunnel (0.3-m TCT). The airfoil model used in testing was CAST-10-2/DOA-2 super-critical airfoil. The Langley 0.3-m TCT has a relatively small cross section of 13 in x 13 in, giving a (h/c) ratio of 1.44 for the same 9 in chord model. The approach employed in the 0.3-m TCT aims towards eliminating the wall effects by using active walls. The top and bottom walls are flexible. By changing the wall shapes during a test in an iterative manner, the wall interference effects are reduced. The method employed to change the wall shapes is the adaptive wall technique. The current test program provided an opportunity to validate the adaptive wall technique in the 0.3-m TCT. The relatively long chord airfoil represents a severe test case to test the efficacy of the adaptive wall technique under cryogenic conditions. The program also involved removal of side wall boundary-layer thus increasing the complexity of the wall adaptation technique. This paper deals with some salient results obtained regarding repeatability of test data and possible residual interference effects. Author

**N90-17658\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

**COMPARISON OF TWO- AND THREE-DIMENSIONAL NAVIER-STOKES SOLUTIONS WITH NASA EXPERIMENTAL DATA FOR CAST-10 AIRFOIL**

R. CHARLES SWANSON, ROLF RADESPIEL, and V. EDWARD MCCORMICK (North Carolina State Univ., Raleigh.) *In its* CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 233-258 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 01/1

The two-dimensional (2-D) and three-dimensional Navier-Stokes equations are solved for flow over a NAE CAST-10 airfoil model. Recently developed finite-volume codes that apply a multistage time stepping scheme in conjunction with steady state acceleration techniques are used to solve the equations. Two-dimensional results are shown for flow conditions uncorrected and corrected for wind tunnel wall interference effects. Predicted surface pressures from 3-D simulations are compared with those from 2-D calculations. The focus of the 3-D computations is the influence of the sidewall boundary layers. Topological features of the 3-D flow fields are indicated. Lift and drag results are compared with experimental measurements. Author

## 03

### AIR TRANSPORTATION AND SAFETY

Includes passenger and cargo air transport operations; and aircraft accidents.

#### A90-23924

#### FRICTION MEASUREMENTS UNDER WINTER RUNWAY CONDITIONS

Aerospace Engineering (ISSN 0736-2536), vol. 10, Feb. 1990, p. 32-35.

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Aircraft and ground friction measuring devices for improved measuring techniques and inspection procedures related to tire and runway conditions have been developed, to better understand ground handling performance of aircraft under adverse weather conditions. The program is also aimed at defining relationships between aircraft and ground vehicle tire friction measurements. Major parameters influencing tire friction performance, such as speed, contaminant type and amount, test tire inflation pressure,



### 03 AIR TRANSPORTATION AND SAFETY

and runway surface texture, were evaluated during the test program. Over 200 test runs were made with B-737 and B-727 aircraft on 12 different concrete and asphalt runways, grooved and nongrooved, including porous friction coarse, under dry, truck wet, rain wet, and snow-, slush-, and ice covered surface conditions. Details and charts are provided to illustrate the results obtained.

R.E.P.

#### A90-26018

##### AN ANALYSIS OF FACTORS IMPEDING PASSENGER ESCAPE FROM AIRCRAFT FIRES

I. R. HILL (RAF, Institute of Pathology and Tropical Medicine, Aylesbury, England) Aviation, Space, and Environmental Medicine (ISSN 0095-6562), vol. 61, March 1990, p. 261-265. refs

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The aviation world has long recognized that fires in aircraft are potentially very dangerous, being the cause of considerable mortality and morbidity even in otherwise survivable accidents. The evidence accumulated in the British Airtours Boeing 737 accident at Manchester International Airport on 22 August 1985, and the information acquired as a result of this investigation, reinforce the long held view that protection for passengers is needed. Heat, smoke, and toxic fumes can incapacitate people very rapidly. The time it took for people to die cannot be accurately assessed, but it is likely that all died within 4.5 min of the emergency being declared and probably within 2 min of smoke and flames entering the fuselage. Thus, it is obvious that new measures will have to be taken if lives are to be saved in future events of this nature.

Author

#### A90-26131#

##### CHARGING OF AIRCRAFT - HIGH-VELOCITY COLLISIONS

W. D. KEITH and C. P. R. SAUNDERS (University of Manchester Institute of Science and Technology, England) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 218-222. Research supported by USAF. refs

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A laboratory investigation into the charge transferred to a metal target during high-speed collisions with ice crystals has shown that the charge separated at a speed of 25 m/s is greater than the charge separated at higher speeds under the same cloud conditions. It is suggested that the reduction in charge transfer at high speeds is because of the reduced contact time between the interacting particles. The sign of the charging is negative in conditions of zero liquid water content at all temperatures; the charging is positive at warm temperatures in the presence of liquid water. Thus, aircraft may charge negatively at high altitudes and positively at lower levels when they encounter water droplets.

Author

#### A90-26231#

##### PROBABILISTIC RISK ASSESSMENT AND AVIATION SYSTEM SAFETY

LEONARD A. WOJCIK (Flight Safety Foundation, Arlington, VA) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 402-407. refs

The development of safety indicators for the U.S. air transportation system is examined. Particular attention is given to quantitative indicators based on probabilistic risk assessment and the use of management and organizational factors to handle human performance issues in risk assessment. The three safety goals of the study are: (1) low frequency of accidents and incidents; (2) adequate capability to meet demand; and (3) limited potential for serious human error. The model requirements for an air traffic system based on risk assessment are discussed.

I.F.

#### A90-26254#

##### GENERAL AVIATION PILOT ERROR IN COMPUTER SIMULATED ADVERSE WEATHER SCENARIOS

SCOTT S. POTTER, THOMAS H. ROCKWELL, and C. ELAINE MCCOY (Ohio State University, Columbus) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20,

1989, Proceedings. Volume 2. Columbus, OH, Ohio State University, 1989, p. 570-575. refs

(Contract DTRS57L-85-C-00101)

Flight simulations with computer aided adverse weather conditions are used to study VFR flight into unforecasting instrument meteorological conditions. A weather planner was developed to try to reduce the likelihood of pilot errors in weather information seeking, altitude management, and destination diversion decision making. Flight simulations were conducted with and without a weather planner. The factors that contribute to operational errors are examined, including a lack of trend information, route tunnel vision, a lack of understanding of the overall weather conditions, and altitude selection errors. The results are used to evaluate the effectiveness of the strategic weather planner and to assess pilot knowledge of weather and its significance for safe flight.

R.B.

#### A90-26301#

##### ANOTHER LOOK AT AIRCRAFT ACCIDENT STATISTICS

JEFFERSON M. KOONCE (Illinois, University, Savoy) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 2. Columbus, OH, Ohio State University, 1989, p. 866-871.

The types of statistics pertaining to aircraft accidents are discussed in the framework of useful information contained. It is shown that, using the same data but different formulas, accident statistics can be used to promote differing viewpoints. For example, the impressive safety record of the commercial air carriers over general aviation is often expressed in terms of total accidents per 100,000 hrs of flight or fatal accidents per 100,000 hrs of flight. The differences in the accident rates of these two means of air travel are less when the data are expressed in terms of accidents per number of take-offs. Such data indicate a need to research and quantify those factors that result in the accident data.

I.S.

#### A90-26977#

##### THE EFFECT OF EXPERIMENTAL UNCERTAINTIES ON ICING TEST RESULTS

C. SCOTT BARTLETT (Sverdrup Technology, Inc., Arnold AFB, TN) and ROBERT G. FOSTER (Canadian Forces, Arnold AFB, TN) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 14 p. refs

(AIAA PAPER 90-0665)

Data to evaluate the safe operational limits of aircraft and propulsion systems in icing environments can be obtained during ground testing. Uncertainties in setting or knowing icing test conditions makes accurate interpretation of icing test results difficult. The influence of icing test condition parameter uncertainties for both ice accretion characterization and thermal anti-icing heat rate requirement determination during icing testing are analytically studied. The analysis indicates which parameter uncertainties have the largest influence on the test results. The analysis also indicates that the influence of parameter uncertainties is not the same for ice accretion characterization as for thermal anti-icing heat rate determination. The relationship between free-stream icing conditions and the conditions actually existing at the icing surface of interest is discussed.

Author

#### A90-26986\*# Texas A&M Univ., College Station.

##### A STUDY OF ICE SHAPE PREDICTION METHODOLOGIES AND COMPARISON WITH EXPERIMENTAL DATA

K. D. KORKAN and R. K. BRITTON (Texas A & M University, College Station) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 20 p. refs

(Contract NCC3-626)

(AIAA PAPER 90-0753) Copyright

Current analytical ice shape prediction methods are described and evaluated. The analyses of Gray (1958), Wilder (1969), and Bragg (1982) are compared with the prediction of the LEWICE computer analysis. The effects of time stepping and initial surface roughness on analysis predictions are studied utilizing the prediction methods and flight data. Rime, mixed, and glazed ice shapes at the leading edge of an airfoil are analyzed. It is observed that

there is no change in ice shape prediction if ice accumulation is less than 0.01, a minimum of 2 time steps is need to incorporate time dependent behavior into the analysis, and the LEWICE analysis provided the most accurate predictions. I.F.

#### A90-27424

##### CONTAMINATION OF CABIN AIR BY SYNTHETIC OIL AND BREAKDOWN PRODUCTS

THOMAS A. DICKEY and DONALD E. WILSON (Textron Lycoming, Stratford, CT) SAE, Intersociety Conference on Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 12 p. (SAE PAPER 891455) Copyright

In connection with the development of catalytic converter to eliminate traces of oil from turbine engine and APU bleed air, some experiments were conducted to better understand the compounds present in the cabin air as well as possible compounds originating from the turbine oil. Samples of cabin air were taken from an aircraft in flight and analyzed by means of gas chromatography/mass spectroscopy. The compounds, as determined by this method, were then compared with the compounds found in air which had been passed over synthetic oil (Mil L 23699 type) heated to various elevated temperatures. This paper describes the experiments and presents the data obtained.

Author

**N90-16722#** Sandia National Labs., Albuquerque, NM. Aerospace Projects Div.

##### RISK ASSESSMENT AND ITS APPLICATION TO FLIGHT SAFETY ANALYSIS

DAVID L. KEESE and WILLIAM R. BARTON Dec. 1989 17 p (Contract DE-AC04-76DP-00789)

(DE90-004985; SAND-89-1982) Avail: NTIS HC A03/MF A01  
Potentially hazardous test activities were historically a part of Sandia National Labs mission to design, develop, and test new weapons systems. These test activities include high speed air drops for parachute development, sled tests for component and system level studies, multiple stage rocket experiments, and artillery firings of various projectiles. Due to the nature of Sandia's test programs, the risk associated with these activities can never be totally eliminated. However, a consistent set of policies should be available to provide guidance into the level of risk that is acceptable in these areas. A general set of guidelines is presented for addressing safety issues related to rocket flight operations at Sandia National Laboratories. Even though the majority of this report deals primarily with rocket flight safety, these same principles could be applied to other hazardous test activities. The basic concepts of risk analysis have a wide range of applications into many of Sandia's current operations.

DOE

**N90-16723#** Army Aviation Engineering Flight Activity, Edwards AFB, CA.

##### NATURAL ICING RE-EVALUATION OF THE EH-60A QUICK FIX HELICOPTER Final Report, 25 Feb. - 13 May 1989

DAVID A. DOWNEY, ANDREW J. TAILBY, and JOSEPH L. PIOTROWSKI May 1989 65 p (AD-A214728; USAAEFA-88-06-1) Avail: NTIS HC A04/MF A01 CSCL 01/3

Natural icing flight tests were conducted on the EH-60A helicopter (USA S/N 86-24569) Quick Fix system to establish an icing flight envelope with the AN/ALQ-151(V)2 countermeasures system installed. Eight flights with a total of 11.1 productive test hours were flown in a natural icing environment at Duluth, MN between 25 February and 13 March 1989. Two deficiencies were noted: the design of the electronic countermeasures (ECM) antenna assembly and mount which caused excessive ice-induced oscillations and subsequent component failure and the poor reliability of the integrated inertial navigation system (IINS). Two icing-related shortcomings were noted: the loosening of the direction finding (DF) dipole antennas during flight in icing conditions and the inaccuracy of the liquid water content (LWC) readings of the Rosemount icing rate meter. The poor integration of the IINS and flight instruments which prevented the direct display of TACAN information was also a shortcoming. One previously identified

icing-related deficiency and seven previously identified icing-related shortcomings of the UH-60A/EH-60A helicopter were re-evaluated and remain uncorrected. The EH-60A Quick Fix helicopter, with modified DF antenna insulator housing (part no. 1951-1-4116-4), should be released for flight in moderate icing conditions with the ECM antenna retracted only. GRA

**N90-16724#** Dayton Univ., OH. Research Inst.

##### THE COLLECTION OF NON-CONUS AIRCRAFT ICING DATA ALONG WITH AN IDENTIFICATION OF THE GEOGRAPHICAL AREAS OF POTENTIAL SEVERE ICING AND A STUDY OF A METHOD OF REMOTE DETERMINING ATMOSPHERIC ICING DATA

NICHOLAS A. ENGLER, PATRICK A. HAINES, and CLIFFORD A. CERBUS Jan. 1988 120 p (Contract DTFA03-85-C-00009) (AD-A215055; UDR-TR-88-10) Avail: NTIS HC A06/MF A01 CSCL 01/3

Research was conducted in three areas. Surveys were made of foreign countries and whenever possible aircraft icing data was retrieved that would be suitable for inclusion into the already established FAA/NRL icing data base. Those geographical areas were determined where icing would be a problem for aircraft. And an alternate data collection scheme was developed which could be used in lieu of flying aircraft to obtain icing data. Realistic methods are discussed for identifying potentially severe icing geographical regions of the Northern Hemisphere. A useful method to calculate the liquid water content of a remote region is described. The collection of nonconus aircraft is shown and data is presented.

Author

**N90-16725#** Aeronautical Research Labs., Melbourne (Australia).

##### RAAF ORION AIRCRAFT A9-300 OXYGEN FIRE

S. A. BARTER and L. W. HILLEN 1987 46 p Original contains color illustrations (AD-A215496; ARL-APP-R-84; DODA-AR-004-535) Avail: NTIS HC A03/MF A01 CSCL 01/3

This report summarizes the findings of the investigation into the nature and cause of the fire in RAAF Orion aircraft A9-300. This aircraft was destroyed by a fire which initiated in the oxygen system as the result of an explosion caused by metal ignition.

GRA

**N90-16726#** Centre d'Essais Aeronautique Toulouse (France).

##### ANALYSIS OF INDIRECT EFFECTS OF LIGHTNING ON A METALLIC A 300 WING: TEST REPORT [ANALYSE DES EFFETS INDIRECTS DE LA FOUDRE SUR UNE VOITURE METALLIQUE A 300. PROCES-VERBAL E87/645800]

28 Feb. 1989 25 p In FRENCH (REPT-E87/645800; ETN-90-96078) Avail: NTIS HC A03/MF A01

Lightning simulation tests using currents from 2 to 45 kA are described. The two pseudo axial current returns installed are detailed. Time profiles of the typical simulated lightning parameters are given. An extrapolation method is suggested in order to simplify the aircrafts qualification tests for metallic structures. ESA

**N90-16727#** Centre d'Essais Aeronautique Toulouse (France). Lab. Essais d'Impacts sur Structures.

##### BIRD IMPACT TESTS ON ASYMMETRIC SANDWICH STRUCTURES MADE IN KEVLAR 49 Partial Test Report No. 5 [ESSAIS D'IMPACTS A L'OISEAU SUR STRUCTURES SANDWICH DISSYMETRIQUES EN KEVLAR 49]

17 Aug. 1988 61 p In FRENCH Sponsored by Service Technique des Programmes Aeronautiques, Paris, France (CEAT-NT-10/S/83-5; REPT-S3-4273-5; ETN-90-96079) Avail: NTIS HC A04/MF A01

Angular impacts on flat panels were studied. Several methods to avoid the perforation of the panel were tried. It is found that painting does reduce the bird friction enough to avoid perforation. Improvements are found either by including metallic plates above

### 03 AIR TRANSPORTATION AND SAFETY

the panel surface or by modifying the ply composition and orientation. ESA

**N90-16728#** Centre d'Essais Aeronautique Toulouse (France). **BIRD IMPACT TESTS ON CURVED STRUCTURES OF THE TYPE SANDWICH-KEVLAR-NIDA FOR NORMAL AND ANGULAR SHOOTING** Partial Test Report No. 4 [ESSAIS D'IMPACTS A L'OISEAU SUR STRUCTURES COURBES DE TYPE SANDWICH-KEVLAR-NIDA. TIRS NORMAUX ET OBLIQUES]

M. ETCHETO 14 Nov. 1985 72 p In FRENCH Sponsored by Service Technique des Programmes Aeronautiques, Paris, France (CEAT-NT-10/S/83-4; REPT-S3-4274-4; ETN-90-96080) Avail: NTIS HC A04/MF A01

Normal or angular impacts on curved panels were studied in complement to similar studies made for flat panels. The resistance for the same number of plies is lower than that of flat plates. For small curvature radius, the resistance is equivalent to that of flat panels. The shape of the perforation is a cross or a star. ESA

**N90-16729#** Lawrence Livermore National Lab., CA. Dept. of Chemistry and Materials Science.

**ANALYSIS OF DAMAGED COMPONENTS FROM DOE SECURITY HELICOPTER N7EG**

CHARLES E. WITHERELL 6 Nov. 1989 23 p (Contract W-7405-ENG-48)

(DE90-004488; UCID-21898) Avail: NTIS HC A03/MF A01

Initial contact with Lawrence Livermore National Laboratory (LLNL) was made on October 16, 1989 through a telephone call by EG and G Energy Measurements organization in Las Vegas, Nevada. This subsequently led to shipment to Livermore of the damaged searchlight components, together with several photographs showing views of the damaged searchlight and its attachment locations on the helicopter. Photographs of an intact and undamaged searchlight assembly in various positions mounted on an operating helicopter were also supplied. The damaged parts were shipped on October 19th with a covering letter dated October 18th. The shipment included two major sub-assemblies: the searchlight body, and its supporting yoke. Accompanying these were several fractured screw-heads and two fractured steel tubes. The objectives of the LLNL investigation, as stated in the covering letter, were to conduct an: analysis of the broken brackets, screws, and other apparatus, and to assist in establishing a failure mode of the assembly. DOE

**N90-17581#** Advisory Group for Aerospace Research and Development, Neuilly-Sur-Seine (France). Propulsion and Energetics Panel.

**AIRCRAFT FIRE SAFETY**

Oct. 1989 408 p In ENGLISH and FRENCH Symposium held in Sintra, Portugal, 22-26 May 1989

(AGARD-CP-467; ISBN-92-835-0529-8; AD-A217575) Copyright Avail: NTIS HC A18/MF A03; Non-NATO Nationals requests available only from AGARD/Scientific Publications Executive

The Symposium was arranged in the following sessions: Review of Fire-Related Aircraft Accidents; Fire Safety Standards and Research Programmes; Aircraft Internal Fires; Aircraft External Fires; Fire Safety of Military Weapon Systems; Fire Hardening by Advanced Materials and Structural Design; Passenger Behaviour in Emergency Situations; and Passenger Protective Equipment. The Technical Evaluation Report and an Addendum are included at the beginning of the Proceedings. Questions and answers of the discussions follow each paper. The purpose was a review of the present state-of-the-art and of the last improvements. Improvements are listed in the conclusions and recommendations of the Technical Evaluation Report and in the Addendum.

**N90-17582#** Federal Aviation Administration, Atlantic City, NJ. Fire Safety Branch.

**INVESTIGATION AND CHARACTERISTICS OF MAJOR FIRE-RELATED ACCIDENTS IN CIVIL AIR TRANSPORTS OVER THE PAST TEN YEARS**

RICHARD G. HILL In AGARD, Aircraft Fire Safety 17 p Oct. 1989

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A number of fire-related accidents and incidents that have occurred during the present decade are summarized. The selection of accidents/incidents was based on information availability and perceived importance of those chosen. A brief summary of accident data for the past ten years is presented. A methodology is shown for logically calculating the effects of cabin fire safety improvements on survivability utilizing past accidents. Eight accidents and four incidents are discussed and their link to safety improvements is described. A call for better information from accident investigations was issued. Author

**N90-17583#** Cranfield Inst. of Tech., Bedford (England).

**AIRCRAFT FIRES: A STUDY OF TRANSPORT ACCIDENTS FROM 1975 TO THE PRESENT**

A. F. TAYLOR In AGARD, Aircraft Fire Safety 19 p Oct. 1989

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A further study is being made, on a world-wide basis, of accident summaries and reports together with recent papers on the various aspects of fire safety. The aim is to compare the period since 1974 with the first twenty years of survivable accidents to turbine powered aircraft as presented to the 1975 AGARD Symposium in Rome. While the study is still far from complete it does seem that, although some lessons were learned and improvements were made or are on the way, crashworthiness, fire, and survival remain areas of major concern. Author

**N90-17584#** Canadian Aviation Safety Board, Ottawa (Ontario).

**AIRCRAFT FIRE SAFETY: LEARNING FROM PAST ACCIDENTS**

W. T. TUCKER In AGARD, Aircraft Fire Safety 10 p Oct. 1989

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The real value of aviation occurrence investigations lies in the lessons that can be learned from them to eliminate future accidents or reduce their severity. Past accidents are reviewed with emphasis on the Canadian experience (e.g., Pacific Western Airlines B737 at Calgary International Airport in March 1984). The determination of contributing factors and causes and the identification of safety deficiencies as practiced by the Canadian Aviation Safety Board are differentiated. Also included are areas of current concern and topics requiring further research with a view to further improving aircraft fire safety. Author

**N90-17585#** Federal Aviation Administration, Atlantic City, NJ. Fire Safety Branch.

**DEVELOPMENT OF IMPROVED FIRE SAFETY STANDARDS ADOPTED BY THE FEDERAL AVIATION ADMINISTRATION**

CONSTANTINE P. SARKOS In AGARD, Aircraft Fire Safety 14 p Oct. 1989

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A series of improved fire safety standards for transport aircraft adopted or proposed by the United States Federal Aviation Administration over the past five years are summarized and the technical development of these standards are described. Important test results and analyses employed to develop the new standards are described. Reference is made to technical publications issued by the FAA for each fire safety area. Emphasis is placed on recent and high-impact rulemaking actions such as the heat release standard for large surface area interior panels (based on the Ohio State Rate-of-Heat-Release Apparatus). Other activities summarized include heat resistance evacuation slides, smoke

detectors and fire extinguishers, cargo compartment fire protection, seat cushion fire blocking layers, floor proximity lighting, and crewmember protecting breathing equipment. Author

**N90-17586#** Department of Civil Aviation, An Hoofddorp (Netherlands).

**FIRE SAFETY IN CIVIL AVIATION**

W. KORENROMP *In* AGARD, Aircraft Fire Safety 12 p Oct. 1989

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A large share of all fatalities in civil aviation are caused by fire. For a passenger who considers traveling by air as just another human activity to spend his lifetime, like walking, sporting or sleeping, the risk of flying is more relevant per time unit than per passenger-kilometer. This approach gives also a partial answer why so much should be done to improve safety in civil aviation and to harden the cabin against fire hazards, although commercial air transportation is already considered to be very safe. It is explained what relations exist between preventive measures and measures that mainly enhance survivability. An overview of types of aircraft accidents is given, which points to what types of measures are applicable and effective. The regulatory authorities should gradually develop the airworthiness requirements along these lines, in concert with technological progress and with an emphasis on quality. This will require much attention for cost-benefit analyses for new as well as old safety measures. Author

**N90-17587#** Civil Aviation Authority, London (England).

**A REVIEW OF UK CIVIL AVIATION FIRE AND CABIN SAFETY RESEARCH**

TREVOR J. GILPIN *In* AGARD, Aircraft Fire Safety 4 p Oct. 1989

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A broad overview of current research in the UK into cabin safety is presented with particular emphasis on fire research. The status of passenger protection equipment is reviewed and work in the UK on cabin water sprays is reported. Work on fire blocking layers and small scale tests for the measurement of heat release from aircraft furnishing materials are discussed along with the suppression of fire in cargo compartments. Other topics include work on the mathematical modeling of aircraft cabin fires and on the human factors side, a study of the behavioral aspects of passengers evacuating an aircraft in a competitive situation. Author

**N90-17588#** Federal Ministry of Transport, Bonn (Germany, F.R.). Directorate General for Civil Aviation and Spaceflight.

**OBJECTIVES AND RESULTS OF CABIN FIRE RESEARCH IN GERMANY**

MANFRED WITTMANN *In* AGARD, Aircraft Fire Safety 6 p Oct. 1989

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German activities in aircraft cabin fire safety started in the early 1980's, highlighted by a full scale test in 1986, simulating an aircraft in-flight fire in a modern widebody fuselage. Beginning with a statistical analysis of in-flight fires in the period 1970 to 1982, efforts are presented from the political side to improve aircraft fire safety and outlines the philosophy why Germany concentrated on in-flight fire research. The consequences drawn out of the studies and test results for the design of aircraft cabin interiors and for post-crash fire situations are described. Finally, a view to future activities, including full scale component tests, is presented. Author

**N90-17589#** Air Canada, Montreal (Quebec). Materials and Processes Engineering.

**NEW AIRCRAFT CABIN AND CARGO FLAMMABILITY STANDARDS FOR TRANSPORT CATEGORY AIRCRAFT**

ARTHUR M. WITTENBERG *In* AGARD, Aircraft Fire Safety 9 p Oct. 1989

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In transport aircraft, passenger safety is of paramount importance in establishment of criteria and requirements covering fireworthiness. Thus for cabin and cargo interiors, regulators and aircraft manufacturers have established flammability standards and/or criteria for materials used in these areas. The aircraft manufacturers in turn furnish aircraft with existing state-of-the-art materials technology which will satisfy or exceed the standards and/or criteria requirements. The evolution of these flammability standards to-date and test methods used to ascertain compliance, and an indication of the materials used to meet these standards are outlined. Author

**N90-17590#** Lufthansa German Airlines, Frankfurt (Germany, F.R.). Cabin, Cargo Systems.

**FIRE PREVENTION IN TRANSPORT AIRPLANE PASSENGER CABINS**

UDO WARGENAU *In* AGARD, Aircraft Fire Safety 6 p Oct. 1989

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The most important aspect in air transportation is safety, a part of which is fire prevention. In the environment of the passenger cabin there are different ways to prevent fires. The most obvious one is to provide adequate detection and extinguishing devices. The second way is to design in a fire-preventive manner. The third and most challenging way is to be concerned with fire-resistant materials of the latest state of the art. Although airplanes are designed and built by big airframe manufacturers the airline engineers can take some influence on a fire-hard cabin. Aside from continually requesting changes from aircraft manufacturers the engineers can force the interior equipment vendors to use advanced techniques and materials. This, however, requires a certain degree of know-how and the good intention to assist these vendors. Author

**N90-17591#** Federal Aviation Administration, Atlantic City, NJ. Fire Safety Branch.

**CHARACTERISTICS OF TRANSPORT, AIRCRAFT FIRES MEASURED BY FULL-SCALE TESTS**

CONSTANTINE P. SARKOS and RICHARD G. HILL *In* AGARD, Aircraft Fire Safety 19 p Oct. 1989

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Full-scale transport aircraft cabin fire tests conducted in the United States under postcrash fire conditions are discussed. The logic behind the development of fire test scenarios is described, including a comparison of fire involvement by external fuel fire penetration through an opening or by fuselage burnthrough. Early full-scale tests in the 1960's and 1970's that furnished data on the characteristics of cabin fires are briefly described. Past test activities addressing facets of the fuselage burnthrough problem are also discussed. The impact of environmental factors (such as wind, door opening configuration, and fuselage orientation) on fire penetration through openings and the resulting cabin hazards is discussed on the basis of past test activities. The majority of the data presented are from a recent full-scale test to determine fire/hazard progression in a postcrash cabin fire environment with emphasis on post-flashover conditions, to examine factors affecting occupant survivability, and to evaluate the performance of a protective breathing equipment filter. Past studies addressing important cabin fire characteristics and concepts, such as flashover, stratification, and survivability are discussed and cited. Author

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**N90-17592#** Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Cologne (Germany, F.R.). Inst. fuer Antriebstechnik.

#### **FULL SCALE STUDY OF A CABIN FIRE IN AN A300 FUSELAGE SECTION**

R. DUSSA, R. FIALA, R. WAGNER, and B. ZENSES /In AGARD, Aircraft Fire Safety 16 p Oct. 1989

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Aircraft accidents involving cabin fires have shown that the burning behavior of the cabin materials plays a vital role for the survivability of the passengers. To gain more information on the complex physical and chemical processes in a cabin fire and one the validity of laboratory test methods to evaluate the burning behavior a Cabin-Fire-Safety program was set up. Besides laboratory tests a first full scale cabin fire test was carried out in the scope of this program. For this test an 18 meter long section of a wide body jet was available. Six meters of this fuselage were furnished with cabin materials fulfilling the newest safety standards. In this section gas sampling tubes, thermocouples, radiometers, and smoke density measuring devices were installed. Additionally, the fire was observed and recorded by five video cameras. The burner was situated between the side wall of the cabin and the adjacent seat of the last seat row. After a burning time of 105 seconds a self sustaining fire had developed. The burner was shut off. The fire was extinguished after 365 seconds. Halon was used as an extinguishing agent. Total halon consumption: 1.000 kg. A optical inspection of the cabin had the following result: The seat cushions showed minor to medium burns, except those in the immediate vicinity of the ignition source. The overall weight loss of the seat cushions was approximately 10 percent. The carpet was nearly undamaged. All other parts, as side wall panels, ceiling panels, insulation, air conditioning system, hatracks and so on suffered heavy damage or were destroyed. From gas concentration and temperature readings one could conclude that in the first 60 seconds after ignition survivable conditions prevailed in the cabin. In the following 60 seconds gas concentrations and temperatures reached lethal values. Oxygen concentration decreased rapidly. Visibility fell to zero. Flash-over occurred. The test will be illustrated by video film. Author

**N90-17593#** Civil Aviation Authority, Gatwick (England). Safety Regulation Group.

#### **AIRCRAFT INTERNAL FIRES**

REGINALD D. HALLIDAY /In AGARD, Aircraft Fire Safety 9 p Oct. 1989

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With modern day appliances and equipment a well trained fire service unit should be able to effectively deal with any external fire that may occur at a survivable aircraft accident situation. Incidents that have occurred during recent years show that a positive approach is still needed to what is loosely referred to as the internal fire. New legislation does call for higher fire resistance standards but there will always be the requirement for fire service personnel to deal with this type of problem. A number of attempts were made to address this problem by using various methods to inject either water or halon gas. While these attempts are a possible way forward they have inherent problems. The fire service are faced with a situation over which they have no control and cannot alter in any way. These are: response time, the possible need to deal with an external fire first, passengers evacuating and using exits and denying access or exits that were left open by escaping passengers and will allow any exterior fire to enter. At the present time the United Kingdom is testing a system that does address these problems. It is really two systems in one: onboard water to be used through the cabin area at very low consumption rates activated immediately on impact; and the ability for external services to connect to the system without entering the fuselage and thereby maintain the water sprays while evacuation continues or rescue actions take place. Author

**N90-17594#** Factory Mutual Research Corp., Norwood, MA. **IGNITABILITY OF JET-A FUEL VAPORS IN AIRCRAFT FUEL TANKS**

ERDEM A. URAL, ROBERT G. ZALOOSH, and FRANCO TAMANINI /In AGARD, Aircraft Fire Safety 13 p Oct. 1989  
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Ignitability criteria for fuel vapors in aircraft wing tanks were analyzed. The effects of ambient temperature, tank pressurization, and ventilation on the flammability of the ullage gas mixtures were demonstrated using the ULLAGE computer code. It was shown that in the absence of tank inerting, flammable mixtures are most likely to form at some point during all transport and fighter missions considered. The relative ignitability of ullage vapor mixtures versus the propane-air mixture called for in Military Standard 1757A was analyzed for a lightning strike scenario, for spark ignition and hot surface ignition modes. It was shown that the military standard is not always a conservative evaluation of the ullage ignition hazard. A procedure to determine when the ullage is more readily ignitable than the mixture specified by the Military Standard 1757A was recommended. Author

**N90-17596#** Fire Research Station, Borehamwood (England).

#### **FIRE SCIENCE AND AIRCRAFT SAFETY**

G. COX and J. B. MOSS (Cranfield Inst. of Tech., Bedford, England) /In AGARD, Aircraft Fire Safety 12 p Oct. 1989

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The increased awareness of fire hazards in both passenger transport and buildings has precipitated a reappraisal of models of fire spread embracing both empirical and more fundamentally-based computational approaches. Recent developments are described in the fire science-related aspects of such hazards, contrasting the broad strategies adopted with those applied in the more highly developed combustion technologies. It seeks to demonstrate how current capabilities and future developments, particularly in the computational modeling fire, and driven primarily by the study of fires in building enclosures, might be utilized to guide layout, design and the selection of furnishing materials in aircraft cabins. Examples of current capabilities of computational fluid dynamic models in describing such critical fire phenomena as smoke movement, fire growth, and flame spread are presented. Author

**N90-17597#** Thames Polytechnic, London (England). Centre for Numerical Modelling and Process Analysis.

#### **FORCED AND NATURAL VENTING OF AIRCRAFT CABIN FIRES: A NUMERICAL SIMULATION**

E. R. GALEA and N. C. MARKATOS /In AGARD, Aircraft Fire Safety 9 p Oct. 1989 Prepared in cooperation with National Technical Univ., Athens (Greece)

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A steady-state three-dimensional mathematical field model describing aircraft cabin fires is presented. The fire is modeled by a simple heat source. The simulation is intended to represent nonspreading fires. The computer code uses a Body-Fitted Co-ordinate (BFC) formulation to model accurately the interior of the aircraft that is neither Cartesian nor polar-cylindrical. The dimensions of the fuselage are that of a BOEING-737. The effect of various openings in the fuselage on the temperature distribution within the empty aircraft cabin are investigated. With the cabin fitted with seats, ceiling panels and overhead stowage bins the effect of the aircrafts air-conditioning system on the temperature distribution within the burning fuselage is also examined. Early results suggest that a reverse flow situation (i.e., cold air injected through floor vents and hot air sucked out at ceiling vents) greatly reduces the temperature throughout the fuselage. Author

**N90-17598#** New Brunswick Univ., Fredericton. Dept. of Mechanical Engineering.

**TIME DEVELOPMENT OF CONVECTION FLOW PATTERNS IN AIRCRAFT CABINS UNDER POST-CRASH FIRE EXPOSURE**

G. V. HADJISOPHOCLEOUS, A. C. M. SOUSA, and J. E. E. VENART /In AGARD, Aircraft Fire Safety 14 p Oct. 1989

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The internal transient thermal response of an aircraft cabin to pool fires of different strengths burning outside an open door or fuselage break is simulated. The thermal processes within the cabin are modeled using the fluid flow and energy governing equations. Particular attention is given to the level and time development of the thermal stratification within the cabin over the first 90 s and the time allowed for evacuation of passengers in aircraft certification tests. The numerical simulations for a two-dimensional domain were carried out with advanced numerical techniques based on a control volume formulation combined with boundary-fitted coordinates. Assessments conducted previously on the reliability and accuracy of the algorithm are also briefly outlined.

Author

**N90-17600#** Air Force Aero Propulsion Lab., Wright-Patterson AFB, OH.

**HOT SURFACE IGNITION STUDIES OF AVIATION FLUIDS**

R. G. CLODFELTER /In AGARD, Aircraft Fire Safety 8 p Oct. 1989

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Hot surface ignition temperature testing was performed in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS) located at Wright-Patterson Air Force Base, Ohio. The objective of this test program was to measure Minimum Hot Surface Ignition Temperatures (MHSIT) of five common aircraft fluids (MIL-H-5606 and MIL-H-83282 hydraulic fluids, JP-4 and JP-8 fuels and MIL-L-7808 lubricating oil) using an air-heated bleed-air duct in a high realism test article. A simulated portion of the F-16 engine compartment and F100 engine was inserted into the AENFTS and the five aircraft fluids were injected as spray or drips (streams) onto various locations on the hot bleed-air duct. Ventilation air pressure, temperature, velocity and the flammable fluid flow rate were varied to study their effect on the MHSIT of these fluids. The results show that MHSIT is dependent on both fluid application mode, spray or drip, and application location. MHSIT increased for all test conditions as ventilation air pressure decreased. Increasing ventilation air temperature tended to decrease the MHSIT. Although MHSIT increased with ventilation air velocity increases, this is not a dependable safety criteria since stagnation regions are known to exist in engine compartments. In general, due to the high level of simulation achieved in this program and the wide scope of the test conditions, the results will be of significant value in the fire safety design of future aircraft systems.

Author

**N90-17601#** Royal Aerospace Establishment, Farnborough (England).

**THE STABILITY OF FUEL FIRES**

J. R. TILSTON /In AGARD, Aircraft Fire Safety 11 p Oct. 1989

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The mechanisms of ignition, stabilization, and propagation of aviation turbine fuel fires are examined and discussed in the context of aircraft accidents. This appraisal suggests that the crucial role of a suitably sized aerodynamic stability zone in the stabilization of fuel spray fires was not adequately recognized in the past. It also suggests that the importance of hot surfaces as sources of fuel preparation and ignition was, similarly, neglected. From considerations of the buoyancy and radiative characteristics of even moderately sized pool fires it is concluded that great care is

required in the interpretation of results from smaller experimental fires.

Author

**N90-17602#** Messerschmitt-Boelkow-Blohm G.m.b.H., Munich (Germany, F.R.).

**ONBOARD FIRE- AND EXPLOSION SUPPRESSION FOR FIGHTER AIRCRAFT**

J. WORDEHOFF /In AGARD, Aircraft Fire Safety 11 p Oct. 1989

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The threats to which modern fighter aircraft can be exposed and the state of the art hardware for active and passive fire and explosion suppression systems on the market to combat these threats are described. A summary of forecasted development will be given especially in the field of fire detection systems. An example is given to indicate the progress which was achieved in weight reduction and system improvement over the last 10 years. A fire and explosion suppression system layout will be given for a modern fighter aircraft including its penalty on mass and fuel denial.

Author

**N90-17603#** Naval Air Systems Command, Washington, DC. Subsystems Branch.

**US NAVY AIRCRAFT FIRE PROTECTION TECHNOLOGY**

P. WEINBERG /In AGARD, Aircraft Fire Safety 7 p Oct. 1989

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The U.S. Navy aircraft are routinely exposed to various combat and non-combat threats that could cause either a fire or fuel system explosion. An overview is provided for the design concepts to prevent, detect, and extinguish these fires and explosions. Examples are given of actual designs and equipment installed on current Navy aircraft. An assessment is included on how well these systems perform under test and operational conditions.

Author

**N90-17604#** National Defence Headquarters, Ottawa (Ontario). Accident Investigation Prevention.

**AIRCRAFT FIRE SAFETY IN THE CANADIAN FORCES**

T. A. BAILEY /In AGARD, Aircraft Fire Safety 6 p Oct. 1989

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Flight safety is a prime consideration of the Canadian Forces in its approach to air operations. The aim of the flight safety program is to prevent the accidental loss of aviation resources and this is done by investigation of occurrences, determination of cause, and implementation of preventive measures. Aircraft fire safety is a concern not only to save lives, but resources as well. An overview of aircraft fire safety in the Canadian Forces and how fire safety is approached for the various aircraft types is presented. The transport, maritime, and helicopter fleets are discussed as are procedures for the CF-18. Another aspect of fire safety is that is briefly covered is the crash, fire, and rescue capability (CFR) at military airports to handle an emergency.

Author

**N90-17605#** Boeing Commercial Airplane Co., Seattle, WA.

**FIRE HARDENING OF AIRCRAFT THROUGH UPGRADES OF MATERIALS AND DESIGNS**

J. M. PETERSON, J. C. MCMILLAN, and J. T. LIKES /In AGARD, Aircraft Fire Safety 7 p Oct. 1989

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Commercial air transportation is the safest mode of transport, because the industry and its regulators have emphasized accident avoidance along with backup fire management/control and personnel evacuation strategies when accidents do occur. Regulatory authorities set the minimum safety standards for the



### 03 AIR TRANSPORTATION AND SAFETY

design, manufacture, and operation of aircraft, to which the individual manufacturers and operators add their own unilateral, self-imposed safety criteria. The evolution and status of the FAA regulatory fire safety criteria applicable to aircraft manufacturers, and the additional criteria imposed by the manufacturers on themselves such as D6-51377 for Boeing and ATS 1000.001 for AIRBUS Industries, are discussed. Author

**N90-17606#** British Aerospace Public Ltd. Co., Woodford (England). Airlines Div.

#### **FIRE HARDENING OF AN AIRCRAFT PASSENGER CABIN**

G. J. TRELOAR *In* AGARD, Aircraft Fire Safety 9 p Oct. 1989  
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The implications of fires to that part of a passenger aircraft comprising the fuselage pressure shell are discussed, with particular reference to the passenger cabin and crew areas. The history of materials utilization is reviewed, leading to an overview of the current materials scenario, with particular reference to the use of combustible materials. The particular materials related regulations, covering aspects of fire hardening appertaining to baggage holds, passenger cabin furnishings, and seats, and the additional smoke and toxicity tests introduced by constructors, are discussed. Potential developments to fire harden the fuselage shell to resist an external fire, and cabin furnishings improvements to provide increased fire hardening are exemplified. The interaction between the design aims of the constructors, passenger acceptance, the requirements of the airlines and fire safety are presented finally. Author

**N90-17608#** Messerschmitt-Boelkow-Blohm G.m.b.H., Bremen (Germany, F.R.). Non-Metallic Materials and Processes.

#### **ADVANCED MATERIALS FOR INTERIOR AND EQUIPMENT RELATED TO FIRE SAFETY IN AVIATION**

HANS-DIETER BERG *In* AGARD, Aircraft Fire Safety 7 p Oct. 1989

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The improvements of product safety is continuously under review by aircraft manufacturers. One of the most important fields of safety for passengers and crew members relates to improvements in connection with fires inside and outside the cabin. Naturally, several paths have to be followed simultaneously to achieve the best possible effect. First and foremost there is obviously the endeavor to avoid such accidents from the start. The training of the crew, design of the aircraft and maintenance, airport safety facilities and, last not least, the introduction of improved materials are of vital importance to reduce the danger of accidents with fires. The important aspect of material development and structural design for the interior furnishings and equipment of aircraft is considered. Author

**N90-17609#** Aerospatiale, Toulouse (France).

#### **NEW MATERIALS FOR CIVIL AIRCRAFT FURNISHING**

M. J. FRUSTIE and C. KURAS (Aerospatiale, Suresnes, France) *In* AGARD, Aircraft Fire Safety 4 p Oct. 1989

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In order to improve aircraft safety with respect to fire, in the last few years the authorities have issued several regulations relative to the fire resistance of organic materials used in civil aircraft commercial furnishing, in particular FAR 25 Amendment 61 and FAR 121 Amendment 189. The purpose is to limit the heat release of the materials used for passenger cabin furnishing. These regulations to be applied on aircraft delivered as soon as August 88 are very severe as they prohibit the use of most of the materials which were used up to now. The purpose is to present the various investigations on new materials made at Aerospatiale together with the development of new technologies. Author

**N90-17610#** National Research Council of Canada, Ottawa (Ontario). Inst. for Research in Construction.

#### **HEAT RELEASE RATE MEASUREMENT FOR EVALUATING THE FLAMMABILITY OF AIRCRAFT MATERIALS**

YOSHIO TSUCHIYA *In* AGARD, Aircraft Fire Safety 8 p Oct. 1989

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With the goal of improving fire safety in passenger aircraft, the FAA and Transport Canada have adopted a new test method to evaluate the flammability of aircraft interior materials. The method uses a modified ASTM E906 release rate test apparatus. Experiments have shown that the test is affected by small variations in such factors as the pattern of airflow in the combustion chamber, the number and position of pilot flames and certain characteristics of the sample such as flame retardancy and physical construction. The various factors affecting the test are discussed. Of particular interest is a comparison between the thermal method and the oxygen consumption method of HRR measurement. The oxygen consumption method is recommended. Author

**N90-17611#** Factory Mutual Research Corp., Norwood, MA.

#### **FLAMMABILITY TESTING OF AIRCRAFT CABIN MATERIALS**

A. TEWARSON and R. G. ZALOSH *In* AGARD, Aircraft Fire Safety 12 p Oct. 1989

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Before the new Federal Aviation Administration flammability regulations for aircraft cabin materials were announced, various laboratory flammability tests were conducted on generic aircraft panel materials. Besides convective heat release rates and smoke optical densities, which are included in the new regulations, the tests included material ignitability, fire propagation rates, chemical heat release rates, and toxic gas generation rates. Data obtained using different test methods often differ significantly for the same generic panel material. For example, critical heat fluxes for ignition as measured in the NIST Ignition Apparatus are 16 percent to 110 percent higher than those measured in the FMRC apparatus. In the case of fire propagation, test data are reported for electrical cables as well as panel materials. The cable fire propagation rates are correlated against a fire propagation index based on heat release rate and ignitability data. These data may be useful in assessing the in-flight fire hazard of various cabin materials. In the case of heat release rates per unit surface area, if data from different test facilities are normalized by incident heat flux and compared in terms of the ratio of chemical, and convective heats of combustion to the effective heat of gasification, there is agreement to within at least one significant figure for most materials. Aircraft panel material smoke generation potential, as measured by mass optical density, is shown to be highly dependent on the light source and the ventilation conditions in the fire test. Since these conditions differ substantially for post-crash fires and in-flight fires, flammability guidelines for smoke generation, toxicity, and corrosivity during in-flight fires may entail different test methods than currently used to screen cabin materials for post-crash fire survivability. Author

**N90-17620\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

#### **ANALYSIS OF THE NATIONAL TRANSONIC FACILITY MISHAP**

EDWIN L. FASANELLA (Lockheed Engineering and Sciences Co., Hampton, VA.) and MARTHA P. ROBINSON Jan. 1990 15 p  
(NASA-TM-101686; NAS 1.15:101686) Avail: NTIS HC A03/MF A01 CSCL 14/2

The nonlinear dynamic finite element code DYNAMIC Crash Analysis of STRUCTURES (DYCAST) was used to model an accident scenario that occurred at the National Transonic Facility (NTF) wind tunnel. A post mishap investigation revealed that a total of five upstream bulkhead fairing plates were missing, three in one location and two in another. These plates were drawn into the

wind tunnel's composite fan blades causing extensive damage. A DYCAST model was developed to determine if one-half of a small thermal shield flange clamp, weighing approximately 2.7 lbs., could have spun off the NTF drive shaft and impacted the bulkhead fairing plates with sufficient energy to cause failure of the attachment bolts. The clamp was presumed to have spun off at a tangent from the NTF drive shaft at a velocity of 1624 in/sec (drive shaft rotating at 580 rpm). The DYCAST analytical model predicts that impact of the 2.7 lbs projectile failed all of the bolts in two of the fairing plates allowing them to escape from the bulkhead ring with a low velocity of a few in/sec. Author

**N90-17621#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**DEVELOPMENT OF AN AUTOMATIC GROUND COLLISION AVOIDANCE SYSTEM USING A DIGITAL TERRAIN**

**DATABASE M.S. Thesis**

GREGORY W. BICE Dec. 1989 152 p  
(AD-A216247; AFIT/GAE/ENY/89D-03) Avail: NTIS HC  
A08/MF A01 CSDL 01/2

Several ground collision avoidance systems (GCAS) have been developed to warn the pilot of a potential collision with the terrain if some action is not taken. All current systems have shortcomings pertaining to the sensors that are used and the recovery maneuver that is flown. The USAF is evaluating the potential of digital terrain databases for onboard navigation and terrain avoidance in combat aircraft. The purpose of this thesis was to develop a control system for performing terrain avoidance using a simulated terrain database. This study was conducted for an F-16 aircraft in level flight at 0.6 Mach and sea level conditions. A state-space model of the aircraft and its flight control system was developed using aircraft control derivatives, an F-16 control law diagram, and traditional linearization techniques on the aircraft equations of motion. A control system for implementing terrain avoidance was derived based on the look-ahead capability of the terrain database. Control system response was evaluated using a simulated terrain obstacle and various look-ahead distances on the terrain database. Results indicated that a 1200 foot, or roughly 1.8 second, look-ahead distance provided good improvement in terrain avoidance capabilities for the F-16 compared to looking strictly downward from the aircraft for terrain information. GRA

## 04

## AIRCRAFT COMMUNICATIONS AND NAVIGATION

Includes digital and voice communication with aircraft; air navigation systems (satellite and ground based); and air traffic control.

**A90-23994**

**THE DISADVANTAGES OF GPS - COMPARATIVE STUDY OF SOLUTIONS ADAPTED TO CIVIL AVIATION [INCONVENIENTS DU GPS - ETUDE COMPARATIVE DES SOLUTIONS ADAPTEES A L'AERONAUTIQUE CIVILE]**

J.-M. DURAND (CNES, Paris, France) (Royal Institute of Navigation, Colloquium on Satellite Navigation, London, England, Oct. 17-19, 1989) Navigation (Paris) (ISSN 0028-1530), vol. 38, Jan. 1990, p. 34-46. In French. refs  
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GPS will be an extremely useful satellite-based navigation system usable as a sole means of navigation for most aeronautical flight phases, thus providing substantial savings on aircraft operating costs. However, GPS has three major disadvantages for civil aviation: (1) insufficient system integrity, since satellites can transmit erroneous information for two hours before being repaired or neutralized; in this case, many simultaneous users of the satellite can derive false positions and be unaware of the problem; (2) availability restricted by the limited number of satellites; users are then unable to obtain a position fix or else obtain a result with significantly degraded performance; and (3) deliberate

spatiotemporal degradation of system performance. The different techniques are discussed and different qualitative criteria are used to assess their suitability for civil aviation applications. This study leads to the recommendation of a system to monitor the status of the GPS satellites and broadcast the information to users.

R.E.P.

**A90-23995**

**INTEGRATED NAVIGATION - EMPLOYING LIRU/GPS [LA NAVIGATION INTEGREE - INERTIE A LASER/GPS]**

RANDOLPH HARTMAN (Honeywell, Inc., Minneapolis, MN) (Royal Institute of Navigation, Colloquium on Satellite Navigation, London, England, Oct. 17-19, 1989) Navigation (Paris) (ISSN 0028-1530), vol. 38, Jan. 1990, p. 48-63.

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A system combining a laser inertial reference unit (LIRU) and a GPS sensor unit (GPSSU) has been developed and tested. The two navigation devices have been integrated using a hybrid processor card located in the LIRU. The system provides pure inertial navigation data, pure GPS navigation data, and a hybrid navigation solution. All of the navigation solutions are output on a single standard ARINC429 output bus from the LIRU or using the ARINC429 and GPSSU separately. A description is given of the HG1050 LIRU, the HG2021, the HG2021 GPSSU, and the limitations and characteristics of the individual system components. The limitations of the stand-alone units are resolved through the integration of the sensor data from the two systems as shown in the test results. Further information defines the hardware architecture used in the system and outlines the method by which each of the three navigation solutions are computed. The characteristics of the navigation outputs and the advantages of the integrated design approach are reviewed. Test data are then presented to validate the conclusions.

R.E.P.

**A90-24003#**

**PERFORMANCE STUDY OF AN INTEGRATED NAVSTAR GPS/SINS NAVIGATION SYSTEM**

E. ZHENG and SHIHONG NI (Northwestern Polytechnical University, Xian, People's Republic of China) Northwestern Polytechnical University, Journal (ISSN 1000-2758), vol. 8, Jan. 1990, p. 27-34. In Chinese, with abstract in English. refs

The synergistic effect obtainable by integrating a Strapdown Inertial Navigation System (SINS) with a GPS receiver is discussed. Kalman filter design, system configurations, and performance evaluation are emphasized. A specific example is analyzed and used to develop a comprehensive digital computer simulation and to develop covariance analysis results which demonstrate the improved performance of the proposed integrated system. C.D.

**A90-25495**

**THE TREND IN NAVAIDS INSPECTION IS TO AUTOMATIC OPERATION**

DAVID C. CULLEN (LTV Corp., Sierra Research Div., Buffalo, NY) ICAO Bulletin (ISSN 0018-8778), vol. 44, Oct. 1989, p. 13-15.  
Copyright

Current flight inspection systems used in the present flying environment are reviewed. Navigational aids used to fly under both VFR and IFR conditions must be inspected on a periodic basis to ensure that accuracy and standards are maintained. Flight inspection systems can be grouped into three categories, depending on the degree of automation used to perform these tasks: manual, semiautomatic, and fully automatic. The three systems are further evaluated and compared. It is noted that the trend in flight inspection systems is moving toward automatic.

R.E.P.

**A90-25496**

**PROSPECTS ARE GOOD FOR USING ATC RADAR TO DETECT BIRDS**

N. IU. ROZIN and N. G. MISHCHENKO (Scientific Experimental Centre for ATC Automation, USSR) ICAO Bulletin (ISSN 0018-8778), vol. 44, Oct. 1989, p. 19, 20.

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Among all the environmental elements having an impact on flight safety, birds are the leading factor in the number of incidents caused. Facilities presently available do not make it possible to avert bird strike hazards in all phases of flight. Recent research indicates that, using radar, it becomes possible to detect birds in advance, and at the same time to forecast the points at which the flight paths of the birds will cross regular aircraft routes. Several possible improvements are offered to enhance the prospects of bird avoidance in flight. R.E.P.

### A90-25561

#### THE US AIR TRAFFIC CONTROL SYSTEM ARCHITECTURE

MARTIN T. POZESKY (FAA, Washington, DC) and MICHAEL K. MANN (Martin Marietta Air Traffic Systems, Washington, DC) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1605-1617. refs

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The general architecture of the US National Airspace System (NAS) is presented. Background on the overall air traffic control (ATC) system's history is given as prologue to descriptions of the major elements of the NAS Plan, the US Federal Aviation Administration's current effort to upgrade and modernize the ATC system. Technologies central to achieving the planned end-state configuration for each element are characterized in terms of their functional impact and potential benefit. Communications, navigation aids, weather support, surveillance, and maintenance systems are all undergoing significant technology upgrade. Digital processing capabilities and communications technology lead the way in permitting this modernization program to become reality. Significant consolidation efforts are yielding a much more cost-effective, responsive, and flexible ATC environment. I.E.

### A90-25562

#### NATIONAL AIRSPACE SYSTEM DEMAND AND CAPACITY MODELING

IGOR FROLOW and JOSEPH H. SINNOTT (Mitre Corp., McLean, VA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1618-1624.

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The US Federal Aviation Administration (FAA) has undertaken an effort to model and analyze the performance of the National Airspace System (NAS), a system that encompasses the nationwide airport and airspace network in the United States. This effort and the resulting capability, called the National Airspace System Performance Analysis Capability (NASPAC), are based on operations research and computer-modeling techniques. The authors provide a detailed description of a discrete-event simulation model of the NAS developed as part of the NASPAC project. Special emphasis is placed on the model's representation of the airport and airspace entities that constitute the NAS and the airspace user demand. The authors present the results of an initial analysis of the possible impact of a proposed new airport at Denver, CO, and conclude with a discussion of the potential future direction of NASPAC. I.E.

### A90-25565

#### ADVANCED TRAFFIC MANAGEMENT SYSTEM AUTOMATION

MANUEL F. MEDEIROS (DOT, Transportation Systems Center, Cambridge, MA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1643-1652. Research supported by Unisys Corp. and FAA.

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The Transportation Systems Center (TSC) of the US Department of Transportation utilized state-of-the-art advancements and pioneered automation concepts in delivering the Enhanced Traffic Management System (ETMS), which is serving the nationwide needs of the Federal Aviation Administration's (FAA's) Traffic Management System. The author describes a multiple-part computer complex that supports new concept developments while permitting tested concepts and newly automated functions to be quickly implemented and used operationally by the FAA in daily traffic management activities. Noting the impact of ETMS, an explanation of traffic management functions highlights the role of

automation. A description of the five-phase TSC R&D program is followed by explanations of the innovative aircraft situation display and how the ETMS works. The ETMS distributed architecture design, redundancy, networking, and fail-safe characteristics are presented, leading up to the achievement of a compressed life cycle to operational service. The author highlights design factors contributing significantly to the rapid development, low cost, flexible system design, operational integrity, and timely operational enhancements. I.E.

### A90-25568

#### ATC GROUND COMMUNICATIONS SYSTEM OPTIMIZATION TECHNIQUES

LEE MERRY BROWN, DAVID G. HAMRICK, and LEONE C. MONTICONE (Mitre Corp., McLean, VA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1674-1683.

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The authors address the optimization of three major components of the US Federal Aviation Administration's (FAA's) hybrid leased/owned ground communications system supporting air traffic control (ATC). The optimizations are performed with respect to cost, performance, and reliability. First, optimization of the radio communications link (RCL) backbone microwave transmission system are discussed. A heuristic optimization procedure that minimizes cost subject to capital cost and availability constraints is presented. Second, two levels of user access network (UAN) optimization are discussed. The first level is to optimize the selection of RCL sites to open as drop-and-insert points for access by private leased-line UANs. The second level is to optimize the selection of transmission media used for implementing UANs. A dynamic programming method is presented for identifying FAA facilities where low-density microwave UANs are cost-effective. Third, optimization of the National Airspace Data Interchange Network (NADIN) II packet data switching system is discussed. Because this network will use the FAA-owned RCL transmission resources, the primary measures for optimization are performance and reliability instead of cost. Two methods are presented for this problem: an analytic method and a simulation method. I.E.

### A90-25569

#### MODE S SYSTEM DESIGN AND ARCHITECTURE

JOHN L. BAKER (Westinghouse Electric Corp., Baltimore, MD), VINCENT A. ORLANDO (MIT, Lexington, MA), WESLEY B. LINK (Mitre Corp., McLean, VA), and WILLIAM G. COLLINS (FAA, Washington, DC) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1684-1694. refs

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Mode Select (Mode S) is a secondary surveillance radar system that is designed as an evolutionary improvement to the current Air Traffic Control Radar Beacon System (ATCRBS). Mode S provides improved aircraft surveillance through the use of selective interrogation and monopulse processing and provides a ground-air-ground digital data link. The authors provide an overview of the Mode S aircraft surveillance and data link communications characteristics. This includes a description of monopulse azimuth determination, elimination of synchronous garble, time sharing between ATCRBS and Mode S activities, and the monopulse aircraft surveillance characteristics that provide improved ATCRBS performance. The Mode S sensor architecture and design are described, including the techniques used to provide a high level of sensor reliability, error protection, and a fault tolerance capability that supports data link operations. The authors also present an overview of the Mode S data link communications characteristics and a description of the planned data link applications. I.E.

### A90-25570

#### THE USE OF SATELLITE TECHNOLOGY FOR OCEANIC AIR TRAFFIC CONTROL

PETER L. MASSOGLIA, MARTIN T. POZESKY (FAA, Washington, DC), and GUY T. GERMANA (AERA, Inc., Upper Marlboro, MD) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1695-1708. refs

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The authors discuss the use of satellite technology for communications, navigation, and surveillance within the context of providing air traffic services and control to aircraft operating in US oceanic airspace. Particular emphasis is placed on automatic dependent surveillance, a technique that uses satellite communications channels to relay position data generated by an aircraft's on-board navigation system. Using these same channels, reliable, timely, and direct pilot/controller communications can be provided within the oceanic environment. I.E.

#### A90-25571

##### APPLICABILITY OF AN AUGMENTED GPS FOR NAVIGATION IN THE NATIONAL AIRSPACE SYSTEM

LEONARD SCHUCHMAN, BRYANT D. ELROD (Stanford Telecommunications, Inc., Reston, VA), and A. J. VAN DIERENDONCK (Stanford Telecommunications, Inc., Santa Clara, CA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1709-1727. refs  
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The future applicability of the Global Positioning System (GPS) to the National Airspace System (NAS) for user navigation and landing support is discussed. Functional characteristics and performance estimates are presented for several GPS enhancements, including the use of a geostationary satellite L-band repeater, a CONUS calibration network, and pseudolites. Analysis results indicate that an enhanced GPS system can meet US Federal Aviation Administration (FAA) enroute/terminal area navigation and nonprecision approach requirements under conditions which include accuracy degradation due to worst-case satellite failure, selective availability, and signal integrity. Similarly, it is shown that a Category I precision approach and landing requirement is essentially met using two pseudolites per airport. Additional analysis and extensive testing are required to validate the Category I findings. I.E.

#### A90-25573

##### DEVELOPMENT AND OPERATION OF THE TRAFFIC ALERT AND COLLISION AVOIDANCE SYSTEM (TCAS)

THOMAS WILLIAMSON (FAA, Washington, DC) and NED A. SPENCER (Mitre Corp., McLean, VA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1735-1744. refs  
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The authors describe the development of the Traffic Alert and Collision Avoidance System (TCAS), provide a description of the TCAS II system operation, offer results of operational evaluations conducted in cooperation with Piedmont, United, and Northwest Airlines, and provide the status and progress of the TCAS implementation. In recent years, the TCAS effort has focused on concepts that make use of the radar transponders carried by aircraft for ground air traffic control purposes. A transponder-based collision avoidance system can provide immediate protection against the vast population of aircraft already equipped with either the current Air Traffic Control Radar Beacon System (ATCRBS) transponder or the new Mode S transponder. The TCAS concept encompasses a range of capabilities, including TCAS I, which provides traffic advisories (bearing, range, and relative altitude) to assist the pilot in visually acquiring the threat aircraft, TCAS II, which provides traffic and resolution advisories (recommended escape maneuvers) in the vertical plane, and TCAS III, which provides traffic and resolution advisories in both the vertical and horizontal planes. I.E.

#### A90-25574

##### AIRCRAFT INTERFACE WITH THE FUTURE ATC SYSTEM

DELMAR M. FADDEN and ROBERT W. SCHWAB (Boeing Commercial Airplanes, Seattle, WA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1745-1751. refs  
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The authors address the next transition period for navigation by outlining how the advantages of improved navigational accuracy can benefit both the individual aircraft and the air transportation system despite a mixed environment. The development of advanced navigation, flight planning, performance optimization, automatic guidance, and other capabilities in current and future

flight management systems, together with the availability of digital communications between the airplane and ATC (air traffic control), suggests the need to review the potential airplane contributions to the ATC system of the future. A number of application areas utilizing current airborne flight management technology have been proposed for use with ATC that could provide significant operational benefits. These include: time-navigation applications in traffic management; multisensor navigation to provide automatic dependent surveillance; improved precision for approach, missed approach, and departure procedures; and improved navigational accuracy supporting reduced airway widths, holding pattern airspace, and aircraft separation standards. Several examples of operational benefits for operators and ATC during the transition period are identified, and the need for integrating these features into future ATC capabilities and procedures is stressed. The public's investment in the National Airspace System (NAS) plan, together with the airlines' investments in modern flight management technology, requires commensurate improvements in total air transportation system performance. I.E.

#### A90-25575

##### DESIGN CONSIDERATIONS FOR ACHIEVING MLS CATEGORY III REQUIREMENTS

SEYMOUR EVERETT (FAA, Washington, DC), KELLY MARKIN, PETER WROBLEWSKI, and MELVIN ZELTSER (Mitre Corp., McLean, VA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1752-1761. refs  
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The authors examine Microwave Landing System (MLS) ground equipment design considerations for achieving the requirements for Category III landing operations. Specifically addressed are accuracy, continuity of service, and integrity requirements. Accuracy near the touchdown region is achieved by providing adequate transmitter power, sufficiently small antenna beamwidth, low effective sidelobes (e.g., by introducing a degree of randomness in the dynamic sidelobes and by using a directive element pattern), and, in the azimuth antenna, by shaping the vertical pattern. High continuity of service is achieved by using a high-reliability design, through redundancy of critical elements, by providing an uninterruptible power supply, and by incorporating prealarm warnings. High integrity is achieved by providing an appropriate configuration of redundant monitors, a capability to verify monitor performance periodically, a high-reliability control circuit, and sufficiently independent implementation of transmitter, monitor, and control functions. I.E.

#### A90-25702#

##### RAPSAT - APPLICATION OF ONBOARD PROCESSING FOR COMMUNICATION AND SURVEILLANCE IN AIR TRAFFIC CONTROL

C. SHIVELY, R. BRAFF, W. HERSHEY, T. HSIAO, and K. VIETS (Mitre Corp., McLean, VA) IN: AIAA International Communication Satellite Systems Conference and Exhibit, 13th, Los Angeles, CA, Mar. 11-15, 1990, Technical Papers. Part 2. Washington, DC, American Institute of Aeronautics and Astronautics, 1990, p. 846-857. refs  
(AIAA PAPER 90-0883) Copyright

The proposed Ranging and Processing Satellite (Rapsat) would provide surveillance and data-link services for aviation. A feasibility study shows the system can serve approximately 50,000 peak instantaneous users with a total L-band spectrum of about 8 MHz. The results are based on realistic message sizes and frequencies, plus the projected geographic distribution of air traffic over the U.S. in the year 2010. The system offers both automatic dependent surveillance and cooperative independent surveillance services. It employs two GEO satellites, a crosslink for coordination between the satellites, an onboard data processor for each satellite, and direct access to the satellites from ATC facilities. Author

#### A90-26338

##### GLOBAL POSITIONING SYSTEM: ARRIVAL IN THE FLEET - A GPS AN/SRN-25(V) RECEIVER ASSESSMENT

PETER J. KARCZ (Vitro Corp., Combat Support Engineering Dept.,

Silver Spring, MD) Vitro Technical Journal, vol. 8, Winter 1990, p. 79-87. refs  
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In order to evaluate the USN's initial reaction to the newly installed AN/SRN-25(V) receiver and the equally novel GPS system, a survey has been conducted of fleet users with a view to the prospective effects of the new equipment on naval strategy and tactics. When GPS satellites are available at a given area of naval deployment, most users were found to rely on GPS exclusively. Naval message responses and personal interviews have indicated that the AN/SRN-25(V) receiver is used not only as a means of GPS navigation, but also as a guide in mine-hunting and mine-sweeping operations and as a means of determining battle-group asset positions and estimating target positions. O.C.

## A90-26651

### A WAVEFORM ALIGNMENT APPROACH TO POSITIONING AIRBORNE RADAR-SOUNDING DATA

GUY M. CROSS and GARRY K. C. CLARKE (British Columbia, University, Vancouver, Canada) IEEE Transactions on Geoscience and Remote Sensing (ISSN 0196-2892), vol. 28, Jan. 1990, p. 123-126. Research supported by NSERC. refs  
Copyright

A low-cost approach has been developed for positioning airborne radar-sounding data obtained over regions lacking evident visual features but having well-defined topography. By constraining radar profilometry to match a record of actual topography along the flight track, the method compensates for spatial sampling errors caused by local ground-speed variations. Profile alignment is accomplished using dynamic waveform matching and yields a transformation of the sounding data to geographic coordinates. I.E.

**N90-16730#** Computer Technology Associates, Inc., Colorado Springs, CO.

### FAA AIR TRAFFIC CONTROL OPERATIONS CONCEPTS. VOLUME 7: ATCT (AIRPORT TRAFFIC CONTROL TOWERS) TOWER CONTROLLERS Final Report

J. R. ALEXANDER, V. L. ALLEY, H. L. AMMERMAN, W. S. FAIRHURST, and C. M. HOSTETLER 21 Apr. 1989 790 p (Contract DTFA01-85-Y-010304) (AD-A210455; DOT/FAA/AP-87/01-VOL-7) Avail: NTIS HC A99/MF E06 CSDL 01/5

Operations concepts for the Air Traffic Controllers are presented. How Tower controllers in Airport Traffic Control Towers may perform their operational jobs in the manual, ARTS, TPX-42 environment is described. Separate analysis are presented for the three basic control positions: Local Control, Ground Control, and Clearance Delivery/Flight Data. Included are: Composition Graphs, showing the logical flow of operational tasks performed in response to or anticipation of external Air Traffic Events; a series of analyses of these tasks, including Information Requirements, Cognitive/Sensory Attributes, and Performance criteria; a User Interface Language aggregating system input and output messages in a hierarchical organization; decomposition of tasks to their constituent procedural elements; and traceability between tasks and ATC procedures documents. Data presented are generated and maintained using the Computer-Human Operational Requirements Analysis System (CHORAS). CHORAS includes an automated task data base, specialized graphing capabilities, and display and hard copy output features tailored to the needs of operations concept analysis. GRA

**N90-16731#** Advisory Group for Aerospace Research and Development, Neuilly-Sur-Seine (France). Guidance and Control Panel.

### ADVANCES IN TECHNIQUES AND TECHNOLOGIES FOR AIR VEHICLE NAVIGATION AND GUIDANCE

Dec. 1989 200 p In ENGLISH and FRENCH Symposium held in Lisbon, Portugal, 9-12 May 1989 (AGARD-CP-455; ISBN-92-835-0535-2) Copyright Avail: NTIS HC A09/MF A02; Non-NATO Nationals requests available only from AGARD/Scientific Publications Executive

The following topics are addressed: terrain reference navigation methods; positioning by image processing or Global Positioning System; mission and sensor management; new techniques and algorithms; sensor technology; and systems applications.

**N90-16734#** Hochschule der Bundeswehr, Munich (Germany, F.R.). Dept. of Aerospace Technology.

### AUTONOMOUS AUTOMATIC LANDING THROUGH COMPUTER VISION

R. SCHELL and E. D. DICKMANNS In AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 9 p Dec. 1989

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The automatic autonomous landing approach through computer vision was investigated in a simulation loop with real image sequence processing hardware and software. The use of integral spatio-temporal world models is the presupposition to achieve real time performance with the microprocessors currently available. Results achieved for a business-jet aircraft demonstrate that this set up is powerful enough to solve the problem of autonomous unmanned landing approach. Author

**N90-16735#** Technische Univ., Brunswick (Germany, F.R.). Inst. of Guidance and Control.

### INTEGRATED FLIGHT GUIDANCE SYSTEM USING DIFFERENTIAL-GPS FOR LANDING APPROACH GUIDANCE

THOMAS JACOB and G. SCHAEZNER In AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 10 p Dec. 1989

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Using the satellite based Global Positioning System (GPS) for precision flight guidance, accuracy problems arise due to the influence of dynamic maneuvers on GPS receivers. The error behavior in stationary as well as in dynamic applications is explained. From the error behavior a system concept of an Integrated Flight Guidance System is derived. Different concepts of system integration are explained. The results of a closed loop mechanization of a Kalman filter coupling GPS and INS implemented in the Integrated Flight Guidance System were checked by simulation and flight test results in approach and landings up to CAT 2. Author

**N90-16740#** Air Force Wright Research and Development Center, Wright-Patterson AFB, OH.

### APPLICATION OF MULTIFUNCTION INERTIAL REFERENCE SYSTEMS TO FIGHTER AIRCRAFT

JOHN M. PERDZOCK, JACK JANKOVITZ, and CARLOS A. BEDOYA (McDonnell Aircraft Co., Saint Louis, MO.) In AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 19 p Dec. 1989

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Advanced high performance fighter and transport aircraft depend on reliable, accurate, inertially derived data to perform such subsystem functions as fly-by-wire automatic flight control, fire control, weapon delivery, navigation, guidance, and cockpit displays. These data are currently obtained from inertial reference sensors which are essentially dedicated for each major functional application. Future inertial reference systems must meet the requirements of the functional users and have lower life cycle cost, increased survivability to combat damage, and improve reliability and accuracy. One way to meet these requirements is to use the same sensors to provide kinematic data to all applications. The feasibility of such a system was investigated in the Multifunction Inertial Reference Assembly (MIRA) study. The MIRA is defined by combined inertial requirements for flight control, cockpit display, weapon delivery, and navigation resulting in a

common reference package for multiple users. A history of development activity is shown. Author

**N90-16743#** University Coll. of North Wales, Bangor.

**PARALLEL PROCESSING IMPLEMENTATION OF A FLIGHT CONTROLLER**

P. J. FLEMING, F. GARCIA NOCETTI, C. M. JONES, H. A. THOMPSON, G. INGLE, and E. BALLEY (Royal Aircraft Establishment, Farnborough, England) *In* AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 11 p Dec. 1989

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The feasibility of using a parallel processing transputer-based network, programmed in occam, for the implementation of an aircraft flight control law is investigated. Three techniques to generate the concurrent realization of this control law are described and illustrated together with some indications of their strengths and weaknesses. Software tools were used and developed to automate the mapping of the control law on the transputer system. Integration of the existing control hardware on-board the aircraft and the parallel processing hardware was also addressed.

Author

**N90-16744#** Societe de Fabrication d'Instruments de Mesure, Massy (France). Recherches et Developpements/Navigation-Guidage.

**LOW AIR SPEED COMPUTATION FOR HELICOPTERS: A NEW APPROACH [ANNEMOMETRIE BASSE VITESSE: UNE NOUVELLE APPROCHE]**

YVES PATUREL *In* AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 19 p Dec. 1989 In FRENCH

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In both military and civilian helicopters, it is necessary to monitor airspeed throughout the entire flight envelope. The determination of low airspeeds (less than 25 m/s) is a critical problem because of the limitations of classical anemometric sensors. A solution is proposed based on the derivation of longitudinal and transverse airspeeds from information already available aboard the helicopter: accelerations and attitude control information. The derivation algorithm, called MEDIA, is described along with the results of flight tests.

Transl. by M.G.

**N90-16745#** Defence Research Establishment, Ottawa (Ontario).

**THE DEVELOPMENT OF AN AIRBORNE SYNTHETIC APERTURE RADAR MOTION COMPENSATION SYSTEM**

D. F. LIANG and D. J. DIFILIPPO *In* AGARD, Advances in Techniques and Technologies for Air Vehicle Navigation and Guidance 13 p Dec. 1989

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The Canadian Department of National Defence has developed an airborne Synthetic Aperture Radar Motion Compensation System (SARMCS) for the AN/APS-506 Maritime Search Radar. To attain high quality airborne SAR imagery, the SARMCS must provide accurate information on spurious motion of the antenna phase centre during a SAR scene. This information is used to compensate the radar returns, thereby enhancing the SAR image quality. The SARMCS is effectively an integrated navigation system consisting of a ring laser gyro inertial navigation system (LTN-91), a Decca Doppler radar, a baro-altimeter, and a motion compensation inertial measurement subsystem (MCIMS). The hardware and software configurations of the SARMCS implemented on board a Convair 580 research aircraft are described. In addition, the flight testing approach and some of the simulation and flight test results are presented.

Author

**N90-16748#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**MODELING THE EFFECTS OF THE USE OF GPS (GLOBAL POSITIONING SYSTEM) DERIVED ALTITUDE INDICATION IN THE C-17A AIRDROP SYSTEM M.S. Thesis**

THOMAS R. KOGLER Dec. 1989 80 p (AD-A215366; AFIT/GSO/ENS/89D-9) Avail: NTIS HC A05/MF A01 CSCL 15/6

The McDonnell-Douglas C-17A will use the Global Positioning System (GPS) for horizontal positioning during airdrops. Although GPS is capable of 3-D positioning, the primary reference for positioning in the vertical plane (altitude) is a barometric altimeter with an air data computer. The horizontal accuracy requirement with respect to the computed air release point (CARP) is 100 meters circular error probable (CEP). No accuracy requirement exists in the vertical plane. The purpose of this study is to determine if the vertical positioning provided by GPS allows for better airdrop performance, and to provide guidance in determining an accuracy requirement in the vertical plane.

GRA

## 05

### AIRCRAFT DESIGN, TESTING AND PERFORMANCE

Includes aircraft simulation technology.

**A90-23922**

**PROPULSION SYSTEM INTEGRATION IN HIGH-PERFORMANCE AIRCRAFT**

Aerospace Engineering (ISSN 0736-2536), vol. 10, Feb. 1990, p. 21-25.

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High maneuverability and STOL characteristics likely to be required in next generation aircraft are being studied to minimize interference from propulsion exhaust system integration into the airframe. The relative importance of propulsion system integration is confirmed in test results where the afterbodies of various aircraft comprised from 20-25 percent of the total body length but produced 38-50 percent of the total aircraft drag. Improving maneuvering capability of the aircraft while striving for a low drag configuration usually requires high thrust-to-weight and lift-to-drag ratios. In response to the need to reduce nozzle/afterbody drag and enhance vehicle maneuverability, engineers have conducted a number of studies investigating empennage location, nozzle boattail geometry, and engine thrust vectoring. Studies have been conducted to determine the effects of horizontal and vertical tail locations on the nozzle/afterbody drag. Moving either the horizontal or vertical tails from the aft position to the midposition resulted in a significant reduction in the nozzle drag. Depictions are provided to substantiate the results and conclusions. It is anticipated that studies on the effects of nozzle design, nozzle/afterbody integration, empennage integration, and multiplane vectoring on the aerodynamic characteristics of high performance aircraft will result in technologies which can reduce cruise drag as well as increase maneuverability.

R.E.P.

**A90-23936\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**HUB LOADS ANALYSIS OF THE SA349/2 HELICOPTER**

RUTH M. HEFFERNAN, GLORIA K. YAMAUCHI (NASA, Ames Research Center, Moffett Field, CA), MICHEL GAUBERT (Aerospatiale, Division Helicopteres, Marignane, France), and WAYNE JOHNSON (Johnson Aeronautics, Palo Alto, CA) American Helicopter Society, Journal (ISSN 0002-8711), vol. 35, Jan. 1990, p. 51-63. Previously announced in STAR as N89-13410. refs

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The forces and moments at the rotor hub of an Aerospatiale SA349/2 helicopter were investigated. The study included three

main topics. First, measured hub forces and moments for a range of level flight conditions ( $\mu = 0.14$  to  $0.37$ ) were compared with predictions from a comprehensive rotorcraft analysis to examine the influence of the wake model on the correlations. Second, the effect of changing the blade mass distribution and blade chordwise center of gravity location on the 3/rev nonrotating frame hub loads was studied for a high-speed flight condition ( $\mu = 0.37$ ). Third, the use of higher harmonic control to reduce nonrotating frame 3/rev hub shear forces was investigated. The last two topics were theoretical studies only. Author

**A90-24133  
OPTIMIZATION OF THE RELATIVE THICKNESSES OF A  
HIGH-ASPECT-RATIO WING IN A MULTICRITERIAL  
FORMULATION [OPTIMIZATSIYA OTNOSITEL'NYKH  
TOLSHCHIN KRYLA BOL'SHOGO UDLENENIYA V  
MNOGOKRITERIAL'NOI POSTANOVKE]**

V. M. FROLOV and I. N. SHUMILOVA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 122-127. In Russian. refs

Copyright

The paper examines the problem of the structural strength design of a high-aspect-ratio wing, with its optimization according to several criteria. Particular emphasis is placed on the use of a generalized criterion consisting in the product of particular strength and stiffness criteria with constraints on the aerodynamic characteristics of the wing. This method is then used to design a hypothetical wing. B.J.

**A90-24148  
TAIL ROTOR DYNAMICS DURING THE TRANSLATIONAL  
TURN MANEUVER OF A HELICOPTER [DINAMIKA  
RULEVOGO VINTA PRI RAZVOROTE VERTOLETA S  
POSTUPATEL'NOI SKOROST'YU]**

A. M. VOLODKO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 122-129. In Russian.

Copyright

A method is presented for analyzing the dynamics of gimbal-suspended tail rotor during the translational turn of a single-rotor helicopter. It is shown that, for a certain combination of the kinematic parameters of the turn maneuver, the tail rotor blades may strike against the tail boom. The results of the study may help prevent such a situation during the operation of single-rotor helicopters. V.L.

**A90-24161  
A METHOD FOR CALCULATING THE STIFFNESS  
CHARACTERISTICS OF LARGE-ASPECT-RATIO WINGS WITH  
ANISOTROPIC PANELS IN ACCORDANCE WITH STRENGTH  
ANDAILERON EFFICIENCY REQUIREMENTS [METODIKA  
RASCHETA ZHESTKOSTI NYKH KHKARAKTERISTIK KRYL'EV  
BOL'SHOGO UDLENENIYA S ANIZOTROPNYMI PANELIAMI PRI  
UDOVLETVORENI TREBOVANIAMI PROCHNOSTI I  
EFFEKTIVNOSTI ELERONOV]**

V. S. VOITYSHEN and Z. K. DANILOVA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 65-73. In Russian.

Copyright

The paper is concerned with the problem of selecting functions of the flexural and torsional stiffness characteristics of a large-aspect-ratio swept wing spar. The spar panels have an additional reinforcement at an angle to the structural axis of the wing. The spar mass is minimized for prescribed constraints on strength and aileron efficiency. Results of parametric studies are presented. V.L.

**A90-24218  
PRACTICAL AERODYNAMICS OF THE YAK-42 AIRCRAFT  
[PRAKTICHESKAYA AERODINAMIKA SAMOLETA IAK-42]  
VLADIMIR P. BEKHTR Moscow, Izdatel'stvo Transport, 1989,  
192 p. In Russian.**

Copyright

The geometrical and aerodynamic characteristics of the Yak-42 aircraft and its flight dynamics under different conditions are

reviewed. The discussion covers the aerodynamic characteristics of the Yak-42 swept wing, wing control surfaces and their effect on the aerodynamic characteristics of the aircraft, engine thrust and velocity characteristics, and the effect of temperature and pressure on engine thrust. Attention is also given to the characteristics of horizontal flight, takeoff, climb, descent, and landing; flight under conditions of nonsymmetrical thrust; flight in a turbulent atmosphere; and fuel economy. V.L.

**A90-24272  
FLIGHT TESTING THE F-15E TERRAIN FOLLOWING SYSTEM  
DAVE EIDSAUNE and JOE ZEIS Cockpit (ISSN 0742-1508),  
Oct.-Dec. 1989, p. 4-21.**

Copyright

The F-15E incorporates an advanced terrain following system (TF) and must be thoroughly flight tested before the aircraft can be considered operational. Flight testing the F-15E TF system and results and findings applicable to all terrain following aircraft, present and future are described. The requirements of a TF system are determined by the mission of the aircraft and current defensive capabilities. The very low altitude and high speed flight regime, required the addition of a 100 foot set clearance plane capability. TF system diagrams and cockpit and HUD displays are presented along with accompanying test results. Specific flight test objectives with their results were evaluated to (1) insure proper aircraft/TF system integration and functional operation, (2) verify manual terrain following performance and capabilities, (3) verify automatic terrain following capabilities, including autopilot and navigation system coupling, (4) evaluate mission suitability at night with the HUD FLIR picture, (5) investigate the effect of heavy gross weights on TF performance, (6) evaluate TF performance and suitability in/under the weather and in an ECM environment, and (7) evaluate workload and crew coordination during all phases of TF flight. R.E.P.

**A90-24964  
AVIATION WEEK EDITOR FLIES SOVIET-BASED MIG-29  
FIGHTER**

DAVID M. NORTH Aviation Week and Space Technology (ISSN 0005-2175), vol. 132, Feb. 26, 1990, p. 36-38, 42-45, 48.

Copyright

A Western journalist has been allowed to conduct a flight characteristics evaluation of the Soviet MiG-29 air superiority fighter's MiG-29UB two-seat variant at the Kubinka air base. The reaching of Mach 2 speed at altitude, to simulate an interception mission, was not permitted; neither was the use of the aircraft's HUD. The impression given by the cockpit is essentially that of a last-generation F-4 fighter, with exclusive use of round-dialed analog instruments. Nevertheless, the MiG-29 is judged to be an extremely maneuverable 'dogfighting' aircraft, on a par in most respects with Western air superiority fighters. O.C.

**A90-25169#  
LOW SPEED TESTING AND SIMULATION OF THE STOL AND  
MANEUVER TECHNOLOGY DEMONSTRATOR  
WILLIAM B. BLAKE, DAVID B. LEGGETT, and ANDREW ROMERO  
(USAF, Wright Research and Development Center,  
Wright-Patterson AFB, OH) AIAA, Aerospace Engineering  
Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 23 p.  
refs  
(AIAA PAPER 90-1820)**

A modified full-scale, thrust-reverser-equipped F15-B, with a canard and a set of vectoring/reversing 2-D nozzles, is currently being flight-tested. The STOL and Maneuver Technology Demonstrator (S/MTD) has also been fitted with advanced rough/soft field landing gear and a digital FBW integrated flight-propulsion control system. The S/MTD is designed to land on a 50 x 1500 foot icy runway in a crosswind gusting to 30 kts. Wind tunnel and flight test results are analyzed. R.E.P.

**A90-25174#  
B-2 AERODYNAMIC DESIGN  
HANS W. GRELLMANN (Northrop Corp., Pico Rivera, CA) AIAA,**

Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 5 p.

(AIAA PAPER 90-1802) Copyright

The role of computers, computational fluid dynamics, and wind tunnel testing during B-2 development and validation are presented. It was found that the B-2 exhibits better cruise aerodynamic efficiency than current subsonic transport aircraft. The flying wing provides sufficient internal volume to achieve excellent range/payload performance. It is concluded that the B-2 has demonstrated good augmented stability and control characteristics during flight simulation, over the complete operational flight envelope. R.E.P.

#### A90-25175#

##### THE ROLE OF COMPUTATIONAL FLUID DYNAMICS (CFD) IN AIRCRAFT DESIGN

EDWARD N. TINOCO (Boeing Commercial Airplanes, Seattle, WA) AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 27 p.

(AIAA PAPER 90-1801) Copyright

The application of CFD to aircraft design configurations and its influence on the aircraft development and support process is analyzed. Results indicate that combining CFD and the wind tunnel can achieve design solutions that otherwise would not be found, and can also significantly reduce the length of the design cycle. It is concluded that CFD provides for a better understanding of flow physics, achievement of design solutions that are otherwise unobtainable, and reduction of development flowtime. R.E.P.

A90-25304\*# Analytical Services and Materials, Inc., Hampton, VA.

##### MINIMUM WEIGHT DESIGN OF ROTORCRAFT BLADES WITH MULTIPLE FREQUENCY AND STRESS CONSTRAINTS

ADITI CHATTOPADHYAY (Analytical Services and Materials, Inc., Hampton, VA) and JOANNE L. WALSH (NASA, Langley Research Center, Hampton, VA) (Structures, Structural Dynamics and Materials Conference, 29th, Williamsburg, VA, Apr. 18-20, 1988, Technical Papers, Part 2, p. 1020-1031) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 565-567. Previously cited in issue 12, p. 1826, Accession no. A88-32281. refs

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#### A90-25423

##### A PRACTICAL CO-AXIAL TWIN ROTOR MODEL

C. J. ROBERTS (ML Aviation, Ltd., Maidenhead, England), R. C. JOHNSON (Aston, University, Birmingham, England), and R. A. DAVIS Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 61-68. Research supported by ML Aviation, Ltd. and SERC. refs

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This paper describes the development of a practical Co-axial Contra-rotating Twin Rotor (CCTR) simulation model. A validated single rotor model, employing a closed form solution, was selected as the basis. This was developed to form the nucleus of a simple co-axial model which in turn was improved using results from other published work. The result is an economic to run rotor model, which demonstrates good performance compared to both published papers and practical tests. Author

#### A90-25424

##### AUTOMATIC VIBRATION REDUCTION AT A FOUR BLADED HINGELESS MODEL ROTOR - A WIND TUNNEL DEMONSTRATION

G. LEHMANN and R. KUBE (DLR, Institut fuer Flugmechanik, Brunswick, Federal Republic of Germany) Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 69-86. refs

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A wind tunnel demonstration was performed to show the capabilities of a digital system for automatic vibration reduction by means of higher harmonic control. The implemented adaptive controller is based on a Kalman filter which showed an excellent identification behavior without any tendency of instabilities. This online identification led to a stable operation of the controller over the full speed range at trimmed and untrimmed flight conditions

and also made it capable of handling different feedback signals without changing software. Theoretical aspects of the control algorithm and its realization on a digital computer system are described. The T-matrix which characterizes the actual rotor state is also evaluated and discussed for various flight conditions.

R.E.P.

A90-25425\* California Univ., Los Angeles.

##### HELICOPTER ROTOR DYNAMICS AND AEROELASTICITY - SOME KEY IDEAS AND INSIGHTS

PERETZ P. FRIEDMANN (California, University, Los Angeles) Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 101-121. Research supported by McDonnell Douglas Helicopter Co. refs (Contract NAG2-209; NAG2-477)

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Four important current topics in helicopter rotor dynamics and aeroelasticity are discussed: (1) the role of geometric nonlinearities in rotary-wing aeroelasticity; (2) structural modeling, free vibration, and aeroelastic analysis of composite rotor blades; (3) modeling of coupled rotor/fuselage areomechanical problems and their active control; and (4) use of higher-harmonic control for vibration reduction in helicopter rotors in forward flight. The discussion attempts to provide an improved fundamental understanding of the current state of the art. In this way, future research can be focused on problems which remain to be solved instead of producing marginal improvements on problems which are already understood. Author

A90-26134\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

##### LAMINAR FLOW CONTROL LEADING-EDGE SYSTEMS IN SIMULATED AIRLINE SERVICE

R. D. WAGNER, D. V. MADDALON (NASA, Langley Research Center, Hampton, VA), and D. F. FISHER (NASA, Flight Research Center, Edwards, CA) (ICAS, Congress, 16th, Jerusalem, Israel, Aug. 28-Sept. 2, 1988, Proceedings, Volume 2, p. 1014-1023) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 239-244. Previously cited in issue 03, p. 265, Accession no. A89-13604. refs

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#### A90-26343#

##### DESIGN FOR HYPERSONIC SPEED

P. W. SACHER and E. H. HIRSCHL (MBB, GmbH, Munich, Federal Republic of Germany) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 389-406. refs

Research in West Germany to develop a two-stage orbit transportation system with horizontal take-off capability is reported, focusing on the fundamental design considerations for the first stage of a hypersonic flight vehicle. The specific problems of hypersonic flight are reviewed, including technology requirements. Consideration is given to aerothermodynamics, thermal protection, structures and materials, propulsion, and propulsion integration. The processes and tools used in designing a hypersonic flight vehicle are examined and the configurational aspects of the vehicle are described. R.B.

#### A90-26344#

##### DESIGN PRIORITIES FOR AN AIR-SUPERIORITY FIGHTER

RAJENDRA K. BERA (National Aeronautical Laboratory, Bangalore, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 407-411.

An integrated approach to designing air-superiority fighters is outlined and the design priorities for future fighters are discussed. Consideration is given to a secure cockpit, fire-control system, weapons carriage, stealth, small size, maneuverability, agility, nose pointing, eluding missiles, and persistence. Also the design requirements unrelated to battle are noted. R.B.

#### A90-26350#

##### WIND TUNNEL TESTING OF A HELICOPTER MODEL AT HAL

PRASAD SAMPATH and Z. H. ZAIDI, ED. (Hindustan Aeronautics,



Ltd., Helicopter Design Bureau, Bangalore, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 439-447.

Wind-tunnel tests were carried out on a scale model of a helicopter at the Hindustan Aeronautics Limited wind tunnel to obtain aerodynamic forces and moments for estimating performance, handling qualities, and loads. Rotor wash was not simulated. Flow visualization revealed that the cowling contours influence the interference with the main rotor hub, and that the stub wing can be contoured to minimize interference with the aft fuselage flow. Rotation of the main rotor hub was simulated and indicated an increase in drag of 4.5 percent full scale, with no influence on the moment characteristics of the fuselage. In the presence of the fuselage, the horizontal stabilizer has an efficiency of 65 percent and the vertical stabilizer has an efficiency of 70 percent. The tail boom degrades the performance of the horizontal stabilizer during yawing maneuvers. Author

## **A90-26541 APPLICATION OF A THREE-DIMENSIONAL FINITE ELEMENT GRID GENERATION SCHEME FOR AN F-16 AIRCRAFT CONFIGURATION**

A. ECER, J. T. SPYROPOULOS, and E. BULBUL (Purdue University, Indianapolis, IN) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 741-750.

(Contract AF-AFOSR-80-0258)

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A block-structured finite-element grid-generation scheme is developed to treat complex three-dimensional geometries in a systematic fashion. The solution domain is subdivided in a number of isoparametric superelements of mixed order (blocks) that accurately describe the geometry of each subdomain. High-order interpolation functions are used to generate grids of second-order continuity in each block. This scheme is then applied to generate a complete operational grid around a F-16 aircraft configuration incorporating all the features of that aircraft (e.g., engine inlet, tail, fins, etc.). Major considerations for an accurate description of the geometry and the complex flowfield are discussed. Author

## **A90-26757 FATIGUE SPECTRA DEVELOPMENT FOR AIRBORNE STORES**

VIRGINIA M. GALLAGHER, ROGER L. YORK (SRI International, Menlo Park, CA), and HENRY O. FUCHS IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 135-149. refs

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Recent investigations have indicated that airborne stores may be exposed to a loading environment distinct from that of the aircraft carrying them; however, flight-loads data of sufficient diversity in aircraft, mission types, etc., do not yet exist for stores. The increased service lives of many stores have nevertheless rendered critical the definition of flight-loads spectra for stores fatigue testing on the basis of time-history load data collected on training flights. These data have been processed to yield sequential peak/valley-pair files which upon reorganization generate new mission profiles. O.C.

## **A90-26758 SIMPLIFIED ANALYSIS OF HELICOPTER FATIGUE LOADING SPECTRA**

N. E. DOWLING and A. K. KHOSROVANEH (Virginia Polytechnic Institute and State University, Blacksburg) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 150-170; Discussion, p. 170, 171. Research supported by the U.S. Army. refs

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In employing the Palmgren-Miner rule for irregular loading spectra applied to notched members, it is necessary to employ rain-flow or an equivalent cycle counting method, and also to consider the accelerated damage at low stress levels due to the presence of high-level cycles. Additional interactions between high

and low stress levels, which are associated with local notch mean stress effects, also occur and can be specifically analyzed using the local strain approach. A simplified application of the local strain approach is described that results in upper and lower bounds on life being calculated. This is applied with reasonable success to the standard helicopter loading spectra Helix and Felix, and a much simplified version of Helix is proposed that consists of repetitions of a single typical flight. Author

## **A90-27407 HIGH-TEMPERATURE BOOTSTRAP COMPARED WITH F-15 GROWTH AIR CYCLE AIR CONDITIONING SYSTEM**

D. MATULICH (Allied-Signal Aerospace Co., Torrance, CA) SAE, Intersociety Conference on Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 14 p. refs

(SAE PAPER 891436) Copyright

To further increase the F-15 environmental control system thermal cycle efficiency, an advanced high-temperature, turbine-powered bootstrap air cycle system has been designed to operate directly from the engine bleed air source. The advanced system more fully exploits the engine compressor bleed air energy potential by using the bleed air at maximum pressure and temperature to drive a power turbine. The power turbine precools the bleed air and drives a closed-loop bootstrap air cycle cooling system. This paper introduces the subject through a brief discussion of the recent air cycle system approaches and engine bleed air preconditioning techniques. Thermal system diagrams compare the advanced high-temperature, turbine powered bootstrap with the F-15 growth system at extreme operating conditions. The comparison study shows how the turbine-powered bootstrap offers a substantial improvement in fuel economy, reduces weight, and increases reliability or reduces life-cycle cost when compared to the present system design. R.E.P.

## **A90-27596# STEALTH COMES OF AGE**

ALAN S. BROWN Aerospace America (ISSN 0740-722X), vol. 28, March 1990, p. 16-20, 36.

Copyright

Research in stealth technology is examined. The development of aircraft with reduced radar observability, such as the A-12, U-2, SR-71, F-117A, B-1A, and the B-2 is discussed. The effects of advances in computers, composites, wing shapes, and coatings on the development of more stealth aircraft are described. Consideration is given to the detection of stealth aircraft by Soviet radar. I.F.

## **N90-16751\*# Kansas Univ., Lawrence. PRELIMINARY DESIGN OF A FAMILY OF THREE CLOSE AIR SUPPORT AIRCRAFT**

BRIAN COX, PAUL DARRAH, WAYNE LUSSIER, and NIKOS MILLS 17 May 1989 342 p

(NASA-CR-186070; NAS 1.26:186070) Avail: NTIS HC A15/MF A02 CSCL 01/3

A family of three Close Air Support aircraft is presented. These aircraft are designed with commonality as the main design objective to reduce the life cycle cost. The aircraft are low wing, twin-boom, pusher turbo-prop configurations. The amount of information displayed to the pilot was reduced to a minimum to greatly simplify the cockpit. The aircraft met the mission specifications and the performance and cost characteristics compared well with other CAS aircraft. The concept of a family of CAS aircraft seems viable after preliminary design. Author

N90-16753# Naval Postgraduate School, Monterey, CA. Dept. of Aeronautics and Astronautics.

## **APPLICATIONS OF MODERN CONTROL THEORY SYNTHESIS TO A SUPER-AUGMENTED AIRCRAFT M.S. Thesis**

WALTER L. ROGERS Jun. 1989 165 p  
(AD-A215431) Avail: NTIS HC A08/MF A01 CSCL 12/9

The singular value Bode plot of return difference and loop gain matrices have emerged as useful indicators of multivariable robustness. The H infinity and H2 control theories provide a

systematic procedure for shaping the singular value loop gains of a multivariable feedback control system. It is shown that H infinity control theory, using specified performance objectives and stability constraints, is effective in synthesizing a stabilizing controller for the statically unstable longitudinal dynamics of the X-29. H infinity control synthesis also demonstrates a good ability to cope with a true multivariable design problem such as the multiple, independently controlled surfaces of a super-maneuverable aircraft. However, it is also shown that the control surface deflections and control rates necessary to effect the specified performance levels exceed the performance capabilities of the X-29's actuators. A work-around to the limited actuator performance is provided by penalizing the control input vector more heavily during the problem formulation. This approach, while reducing the actuator performance requirements, results in a limited performance X-29.

GRA

**N90-16755#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**EXPERIMENTAL EVALUATION OF IMPEDANCE CONTROL FOR ROBOTIC AIRCRAFT REFUELING M.S. Thesis**

VERNON W. MILHOLEN 14 Dec. 1989 112 p  
(AD-A215532; AFIT/GE/ENG/89D-32) Avail: NTIS HC A06/MF A01 CSCL 01/3

The robotics program at AFIT is quite advanced in the areas of interest to the Air Force such as human arm emulation and robotic assisted aircraft turnaround. Compliant motion is an enabling technology for these efforts that will prove useful in other applications as well. The refueling task provided the impetus for future development that may soon be used in grasping operations and of course, the completion of the impedance control algorithm implementation. The goals were essentially to build on the foundation laid in previous work by Capt David Duvall and advance the development he began. Specifically, two things were sought: a refueling demonstration, and a more user friendly environment for future progress.

GRA

**N90-16756#** Army Aviation Research and Development Command, Moffett Field, CA. Aeroflightdynamics Directorate.  
**THE RESPONSE OF HELICOPTER ROTORS TO VIBRATORY AIRLOAD**

WILLIAM G. BOUSMAN 14 Nov. 1989 20 p  
(AD-A215678) Avail: NTIS HC A03/MF A01 CSCL 01/3

Structural response data from flight or wind tunnel tests of eight full scale rotors were examined and compared for high speed flight conditions and in the absence of blade stall or maneuvers. Both similarities and differences in the behavior of the rotors were observed, and these findings are useful in determining appropriate tests for development of theoretical methods. Limited use is made of airload measurements and theoretical calculation in examining these data. Major similarities observed in the rotor behavior include: (1) 3/rev vibratory flap bending moments are remarkably similar among all the rotors at high speed; (2) the root oscillatory chord bending induced by lag dampers is similar for three of the articulated rotors despite differences in the damper type; and (3) torsion moment and pitch-link loads show some positive-negative loading over the advancing side of the disk caused by the unsteady pitching moments at the blade tip. Differences that were observed include: (1) the vibratory chord bending moment behavior appears to be dependent on rotor stiffness in part, but differences seen are not easily explained; (2) the CH-53A root oscillatory chord bending moment data do not show the damper induced loads that are seen on the other articulated rotors with hydraulic lag dampers; and (3) the AH-1G torsion response is very different from that of the articulated rotors.

GRA

**N90-16757** ESDU International Ltd., London (England).  
**BODY EFFECT ON WING ANGLE OF ATTACK AND PITCHING**

**MOMENT AT ZERO LIFT AT LOW SPEEDS Abstract Only**  
Nov. 1989 18 p Supersedes ESDU-Aero-A.08.01.07  
(ESDU-89042; ISBN-0-85679-715-4; ISSN-0141-397X) Avail: ESDU

ESDU 89042 gives simple empirical methods of predicting the

change in zero-lift angle and in pitching moment at zero lift due to adding a fuselage of approximately circular section to a swept, cambered and twisted wing. The effects of wing height and of body asymmetry in the aircraft plane of symmetry are considered. It was found that neither Reynolds number nor Mach number below 0.4 was important. Sketches compare both the predicted changes and the values for the wing-body combination with experimental results used in the correlation, and it is found that zero lift angle of attack is predicted to within 0.3 degrees and pitching moment coefficient (based on gross wing area and aerodynamic mean chord) to within 0.1. A worked example illustrates the use of the method, using ESDU 87031 and 87001 to predict wing alone values of zero lift angle of attack and pitching moment respectively, although of course experimental values could be used if available.

ESDU

**N90-16801#** Air Force Systems Command, Wright-Patterson AFB, OH.

**NATIONAL AERO-SPACEPLANE STATUS AND PLANS**

TOM J. GREGORY and H. WRIGHT /n ESA, Progress in Space Transportation p 149-156 Aug. 1989  
Copyright Avail: NTIS HC A22/MF A03

Preliminary results of tests carried out in the design phase of the National Aero-Spaceplane Program are described. The fundamental economic considerations for the development of spaceplanes are reviewed. The advantages and disadvantages of international cooperation in the development of an aero-spaceplane are addressed. The importance of cost considerations in the design of the next generation of launch vehicles is stressed.

ESA

**N90-17552** ARMCON, Inc., Shalimar, FL.

**THE INTEGRATION OF STORES ON MODERN TACTICAL AIRCRAFT: WHERE WE HAVE BEEN, AND WHAT WE SHOULD DO FOR THE FUTURE**

CHARLES S. EPSTEIN /n Nielsen Engineering and Research, Inc., Missile Aerodynamics: NEAR Conference on Missile Aerodynamics 23 p 1989  
Copyright Avail: Issuing Activity

In the years since World War II, although the technological development of aircraft and their weapons has been impressive, there has not been a corresponding program to insure efficient aircraft/weapons compatibility. The lack of a coordinated aircraft/weapons compatibility plan has resulted in spectacularly performing clean aircraft which must suffer significant performance degradations when the stores are installed. The methods of store carriage used in the past, those available to the aircraft and store designers today, and methods which can be used in the future are discussed. Finally, a plea is made for close coordination between the aircraft and the store designers, and for the services to be more realistic in the requirements for tactical aircraft.

Author

**N90-17554** Dornier-Werke G.m.b.H., Friedrichshafen (Germany, F.R.).

**DYNAMIC DERIVATIVES OF MISSILES AND FIGHTER-TYPE CONFIGURATIONS AT HIGH ANGLES OF ATTACK**

HEINZ FUCHS /n Nielsen Engineering and Research, Inc., Missile Aerodynamics: NEAR Conference on Missile Aerodynamics 21 p 1989

Copyright Avail: Issuing Activity

The prediction methodology of dynamic derivatives is presented as derived from semiempirical calculation procedures like USAF Stability and Control Datcom in combination with some modifications necessary for tactical missile configurations at higher angles-of-attack. The main subject is the treatment of longitudinal stability derivatives and of roll damping derivativum. A comparison of theoretical and experimental results is presented. Different dynamic wind tunnel test equipment are explained including the data evaluation theory. Some aspects of modification of the present linear data evaluation method nonlinear terms at high angles-of-attack are shown with an example of a fighter aircraft configuration using the MOD test rig in the Dornier wind tunnel.



## 05 AIRCRAFT DESIGN, TESTING AND PERFORMANCE

Especially, the phenomenon of dynamic lift beyond dynamic stall is shown for sinusoidal oscillations of small reduced frequencies.

Author

**N90-17627\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **SIMULATED-AIRLINE-SERVICE FLIGHT TESTS OF LAMINAR-FLOW CONTROL WITH PERFORATED-SURFACE SUCTION SYSTEM**

DAL V. MADDALON and ALBERT L. BRASLOW (Analytical Services and Materials, Inc., Hampton, VA.) Washington Mar. 1990 40 p  
(NASA-TP-2966; L-16589; NAS 1.60:2966) Avail: NTIS HC A03/MF A01 CSCL 01/3

The effectiveness and practicality of candidate leading edge systems for suction laminar flow control transport airplanes were investigated in a flight test program utilizing a modified JetStar airplane. The leading edge region imposes the most severe conditions on systems required for any type of laminar flow control. Tests of the leading edge systems, therefore, provided definitive results as to the feasibility of active laminar flow control on airplanes. The test airplane was operated under commercial transport operating procedures from various commercial airports and at various seasons of the year.

Author

**N90-17628#** Aeronautical Research Labs., Melbourne (Australia).

### **AN EXAMINATION OF THE FATIGUE METER RECORDS FROM THE RAAF ORION P-3C FLEET Aircraft Structures**

#### **Technical Memorandum**

DOUGLAS J. SHERMAN Apr. 1989 43 p  
(AD-A214000; ARL-STRUC-TM-505; DODA-AR-005-602) Avail: NTIS HC A03/MF A01 CSCL 01/3

Load spectra for the Australian fleet of Orion P-3C aircraft are presented and compared with the ESDU 69023 (discrete gust) and the U.S. MILSPEC A-8861A (power spectral) model, which are here called the baseline models. The turbulence experienced when flying over the sea is about one half of that predicted by the baseline models. The sea appears to reduce the turbulence by a greater amount, and to higher altitudes than indicated by the ESDU model. Transit flights, which involve flying at relatively high altitude over Australia, are about five times as severe as predicted by the baseline models. This supports other observations of a higher than normal incidence of the altitude turbulence (25,000 ft and above) over Australia.

GRA

**N90-17629#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Systems and Logistics.

### **REDUCING C130E HERCULES OPERATING COSTS IN THE ROYAL AUSTRALIAN AIR FORCE AND THE UNITED STATES AIR FORCE BY INCREASING CRUISE SPEEDS M.S. Thesis**

DENNIS G. GREEN Sep. 1989 189 p  
(AD-A215747; AFIT/GLM/ENY/89S-25) Avail: NTIS HC A09/MF A01 CSCL 01/2

The purpose of this research study was to examine a proposal to reduce C130E Hercules operating costs in the Royal Australian Air Force (RAAF) and the United States Air Force (USAF) by increasing cruise speeds. The current fuel conservation policies in the RAAF and USAF do not consider the effect of the policy on aircraft operating costs. RAAF C130E cost data were found to be invalid. The study quantified major differences in the depot servicing, contract servicing, and in-house servicing for RAAF C130E and C130H Hercules aircraft. The study suggests that the RAAF should improve the accuracy of C130E cost data to allow a valid assessment of the operating costs over the aircraft life cycle. The variable maintenance costs were found to be more than double the hourly fuel costs. Flight Manual data and mission profile data were used to show that the USAF could save \$94,613 to \$1,979,227 (U.S.) in 1989 by flying selected missions at 290 knots instead of 280 knots true airspeed (TAS). The sensitivity of the calculated savings to changes in fuel and maintenance prices was also examined. The study concludes that USAF C130E operating costs can be reduced by increasing cruise speeds. The

study recommends that the USAF introduce 290 knots TAS cruise procedures immediately because of the reduction in operating costs and because there are no implementation costs.

GRA

**N90-17630#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Systems and Logistics.

### **THE TECHNOLOGY CHALLENGE OF THE ADVANCED TACTICAL FIGHTER: A STUDY OF THE TECHNOLOGY TRANSITION PROCESS M.S. Thesis**

ROBERT J. GUMMERE Sep. 1989 148 p  
(AD-A216109; AFIT/GSM/LSM/89S-13) Avail: NTIS HC A07/MF A01 CSCL 01/3

This study examined the technology transition process at the Aeronautical System Division between the Wright Research and Development Center (WRDC), and the Advanced Tactical Fighter Systems Program Office (ATF SPO) at Wright Patterson AFB OH. Four groups were surveyed, they included: WRDC, ATF SPO, ASD engineering, and defense contractors. Five Investigative Questions guided the research: (1) how has the operating command contributed in the development and transition of technology; (2) how well have the official and unofficial technology transition processes worked as perceived by laboratory, SPO, EN, and contractor personnel; (3) what organizations are considered important sources of information on new technology, and what is the frequency of contact with those organizations; (4) what influence is the contractor perceived to have on the success or failure of moving technology from WRDC to the ATF SPO; and (5) is the perceived risk of new technology by the SPO a significant barrier in the transition process.

GRA

**N90-17631#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Systems and Logistics.

### **COST EFFECTIVENESS OF COMPOSITE MATERIALS ON THE F-15 AND F-16 AIRCRAFTS M.S. Thesis**

DIANA M. BOCK Sep. 1989 97 p  
(AD-A216353; AFIT/GCA/LSY/89S-3) Avail: NTIS HC A05/MF A01 CSCL 05/3

This thesis sought to determine the cost effectiveness of composite materials by determining the significant cost drivers in a cost estimating model. Based on a review of historical literature and interviews, it was originally suspected that composite materials were not as cost effective as metal structures in terms of maintenance man-hours. The models developed in this project revealed that number of landings, flight hours, and sortie counts were the most significant cost drivers for maintaining the F-4 stabilator system, a metal structure, and the composite materials found on the horizontal and vertical stabilizers of the F-15 and F-16 aircrafts. The stabilator system on the F-4 was most respondent to the three cost drivers, as this structure required significantly more maintenance man-hours than either the F-15 or F-16 parts. The F-16 horizontal stabilizer assembly was also sensitive to the cost drivers found, as this composite part had more maintenance man-hours than the other three composite parts. The F-16 skins, vertical stabilizer assembly and the F-15 torque box, horizontal stabilator assembly showed that regardless of the number of landings, flight hours, or sortie counts, the maintenance man-hours remained constant, within the range of data for this project.

GRA

## 06

### AIRCRAFT INSTRUMENTATION

Includes cockpit and cabin display devices; and flight instruments.

**A90-24200**

#### **AVIATION EQUIPMENT [AVIATSIONNOE OBOUDOVANIE]**

IURII P. DOBROLENSKII, S. M. KASTERSKII, M. S. KOZLOV, V. M. ZONTOV, IURII E. VOSKRESENSKII et al. Moscow, Voenizdat,

1989, 248 p. In Russian.

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The general design, principle of operation, and maintenance of the main aircraft systems are reviewed. In particular, attention is given to automatic control equipment, on-board digital computers, power supply systems, electrical power plant control systems, aerometric systems, and gyroscopic navigation instruments. The discussion also covers automatic flight control systems, life support equipment, air reconnaissance equipment, imaging systems, and flight data recording and processing systems. V.L.

#### A90-24329

##### HIGH RESOLUTION SPECTRUM ANALYSIS FOR AIRBORNE PULSE DOPPLER RADARS

C. NUTHALAPATI (California State University, Fullerton) Microwave Journal (ISSN 0192-6225), vol. 33, Feb. 1990, p. 113, 114, 118 (3 ff.). refs

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Application of an autoregressive (AR) spectral estimation technique to airborne pulse Doppler radar signal processing is described. The maximum entropy spectral analysis method is considered for Doppler filtering. The performance evaluation of an airborne pulse Doppler radar for detection of low flying targets in a dense clutter environment is determined by computer simulations. Results of this AR spectral estimation are compared with the conventional fast Fourier transform (FFT) method. It is shown quantitatively that the AR method offers better resolution and decreased false alarm rate than the FFT method. Computer simulation of X-band pulse Doppler radar signals and clutter is used for performance comparison. Author

#### A90-25494

##### TCAS - A LENGTHY BUT BENEFICIAL DEVELOPMENT EFFORT

ROBERT M. HANDLEY (Bendix/King, Air Transport Avionics Div., Fort Lauderdale, FL) ICAO Bulletin (ISSN 0018-8778), vol. 44, Oct. 1989, p. 9-12.

Copyright

Features of the Traffic Alert and Collision Avoidance Systems TCAS II and TCAS III are discussed. With TCAS II the flight crew receives avoidance-maneuver information in the vertical plane only, taking the form of commands to climb or descend, or to limit the vertical rates of maneuvering. As evolved, the current TCAS III offers resolution advisories, not only in the vertical, but also in the horizontal plane. It will provide for turns, in addition to vertical maneuvers, to significantly reduce the potential for a near-miss or mid-air collision. Diagrams are presented to demonstrate operation of the TCAS system. TCAS systems are being installed with ongoing developments incorporated as they become available, in order to meet the FAA rule by the end of 1991. R.E.P.

#### A90-26374

##### TEMPERATURE INSENSITIVE FIBER COIL SENSOR FOR ALTIMETERS

Y. IMAI, M. A. RODRIGUES, and KELGO IIZUKA (Toronto, University, Canada) Applied Optics (ISSN 0003-6935), vol. 29, March 1, 1990, p. 975-978. Research supported by the University of Toronto. refs

Copyright

A displacement sensor using a pair of flat Panda fiber coils with a 90-deg connection is demonstrated. The dual coils are squeezed differentially. The phase retardations caused by the compression are constructively added, while the retardations caused by the environmental temperature are destructively added, thereby removing the temperature effect. Both the birefringence and loss effects induced by the deformation of the coils are utilized for high-accuracy and emergency detection, respectively. In experiments using 30-turn coils, the guaranteed sensitivity of 357 deg/mm (retardation/displacement) and the long term stability of 4 deg/h (retardation/period) were obtained. Author

#### A90-27409

##### EMBEDDED DIGITAL CONTROL FOR AIRCRAFT ENVIRONMENTAL CONTROL SYSTEMS - A PRACTICAL VEHICLE MANAGEMENT SYSTEM APPROACH

KENNETH R. ERICKSON (Allied-Signal Aerospace Co., Torrance, CA) SAE, Intersociety Conference on Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 12 p. (SAE PAPER 891438) Copyright

Tradeoff studies are presented that show the benefits of integrating environmental control system (ECS) controls into 'embedded' digital ECS architecture interfacing with supervisory computers. An effort is made to show the most practical approach for integrating the environmental control system (ECS) controls into the overall vehicle management system (VMS) design. A discussion of first and second generation ECS digital controls is first presented to provide the necessary baseline configuration factors for the tradeoff studies. The results indicate that optimum benefits are obtained from an integrated, embedded ECS controls design approach. This approach was defined to be an integral part of the ECS rather than part of a general-purpose central computer structure, but was physically implemented in two strategically located enclosures in the aircraft. This configuration represents what is considered a practical approach to the VMS architecture for a major system such as an ECS. It provides the optimum technical approach at minimum cost and schedule risk, while minimizing program contractual problems of software and hardware design rights, data rights, and product liability. R.E.P.

#### A90-27426

##### MICROPROCESSOR CONTROL OF A VAPOR-CYCLE COOLING SYSTEM

CLIVE M. DANBY and ROBERT G. GLASS (Sundstrand Corp., Advanced Technology Group, Rockford, IL) SAE, Intersociety Conference on Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 7 p.

(SAE PAPER 891457) Copyright

A dual microprocessor-based system controller was developed for aircraft environmental control system (ECS) applications. The controller interfaces with all system sensors and actuators, and software process control algorithms maximize system efficiency. Flexibility is built into the design of the controller to enable configuration for a single or dual-evaporator system simply by fitting different programmable memory devices. Existing component technologies were used to minimize hardware cost. Author

N90-16758\*# National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Center, Edwards, CA.

##### PRELIMINARY RESULTS FROM A SUBSONIC HIGH ANGLE-OF-ATTACK FLUSH AIRDATA SENSING (HI-FADS) SYSTEM: DESIGN, CALIBRATION, AND FLIGHT TEST EVALUATION

STEPHEN A. WHITMORE, TIMOTHY R. MOES, and TERRY J. LARSON (Analytical Mechanics Associates, Inc., Hampton, VA.) Jan. 1990 13 p Presented at the 28th AIAA Aerospace Sciences Meeting, Reno, NV, 8-11 Jan. 1990 Previously announced in IAA as A90-19746

(NASA-TM-101713; H-1583; NAS 1.15:101713; AIAA-90-0232)

Avail: NTIS HC A03/MF A01 CSCL 01/4

A nonintrusive high angle-of-attack flush airdata sensing (HI-FADS) system was installed and flight-tested on the F-18 high alpha research flight vehicle. The system is a matrix of 25 pressure orifices in concentric circles on the nose of the vehicle. The orifices determine angles of attack and sideslip, Mach number, and pressure altitude. Pressure was transmitted from the orifices to an electronically scanned pressure module by lines of pneumatic tubing. The HI-FADS system was calibrated and demonstrated using dutch roll flight maneuvers covering large Mach, angle-of-attack, and sideslip ranges. Reference airdata for system calibration were generated by a minimum variance estimation technique blending measurements from two wingtip airdata booms with inertial velocities, aircraft angular rates and attitudes, precision radar tracking, and meteorological analyses. The pressure orifice calibration was based on identifying empirical adjustments to

## 06 AIRCRAFT INSTRUMENTATION

modified Newtonian flow on a hemisphere. Calibration results are presented. Flight test results used all 25 orifices or used a subset of 9 orifices. Under moderate maneuvering conditions, the HI-FADS system gave excellent results over the entire subsonic Mach number range up to 55 deg angle of attack. The internal pneumatic frequency response of the system is accurate to beyond 10 Hz. Aerodynamic lags in the aircraft flow field caused some performance degradation during heavy maneuvering. Author

**N90-17632\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

### **A HEAD UP DISPLAY FORMAT FOR APPLICATION TO V/STOL AIRCRAFT APPROACH AND LANDING**

VERNON K. MERRICK, GLENN G. FARRIS, and ANDREJS A. VANAGS (SYRE Corp., Moffett Field, CA.) Jan. 1990 76 p (NASA-TM-102216; A-89215; NAS 1.15:102216) Avail: NTIS HC A05/MF A01 CSCL 01/4

A head up display (HUD) format developed at NASA Ames Research Center to provide pilots of V/STOL aircraft with complete flight guidance and control information for category-3C terminal-area flight operations, is described in detail. These flight operations cover a large spectrum, from STOL operations on land-based runways to VTOL operations on small ships in high seas. Included in this description is a complete geometrical specification of the HUD elements and their drive laws. The principal features of this display format are the integration of the flightpath and pursuit guidance information into a narrow field of view, easily assimilated by the pilot with a single glance, and the superposition of vertical and horizontal situation information. The display is a derivative of a successful design developed for conventional transport aircraft. The design is the outcome of many piloted simulations conducted over a four-year period. Whereas the concepts on which the display format rests could not be fully exploited because of field-of-view restrictions, and some reservations remain about the acceptability of superimposing vertical and horizontal situation information, the design successfully fulfilled its intended objectives. Author

## 07

## AIRCRAFT PROPULSION AND POWER

Includes prime propulsion systems and systems components, e.g., gas turbine engines and compressors; and on-board auxiliary power plants for aircraft.

### **A90-23758# NUMERICAL OPTIMIZATION OF AXIAL COMPRESSOR DESIGNS**

RICHARD M. HEARSEY (Boeing Commercial Airplanes, Seattle, WA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-14)

An application of numerical optimization to axial compressor design is illustrated in this paper. A design-point efficiency model is coupled to an optimization routine to create a method of deriving designs that are optimized for efficiency. Numerous constraints, many non-linear, are applied to control parameters to which the efficiency model is insensitive, such as rotor hub choking. The High Pressure Compressor of the Energy Efficient Engine that was designed for NASA by the General Electric Company is used as a vehicle to demonstrate the potential merits of the procedure; design-point efficiency increases of several points are projected for optimized designs. Author

### **A90-23764# DEVELOPMENT OF A DUAL FUEL INJECTOR FOR A GAS TURBINE COMBUSTOR**

B. C. SCHLEIN, T. G. FOX, and C. J. PUMA (United Technologies Corp., Pratt and Whitney Group, East Hartford, CT) ASME, Gas

Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. (ASME PAPER 89-GT-25)

A dual fuel nozzle has been developed for the FT-8, an industrial version of Pratt and Whitney's JT8D engine. The nozzle is configured with a natural gas passage wrapped around a liquid air blast nozzle. The paper describes the development of the nozzle in a single can rig in a high pressure facility. A test program was conducted which parametrically varied the swirl angle of the air passage swirlers. Stability, smoke, and exit gas temperature profile data were acquired with Jet A, diesel and methane fuels and used to optimize the design. An optical probe was used to observe starting, blowout and transition from liquid to gaseous fuels and vice versa. Author

### **A90-23765# RESONANT STRESS DETERMINATION OF A TURBINE BLADE WITH MODAL DAMPING AS A FUNCTION OF ROTOR SPEED AND VIBRATIONAL AMPLITUDE**

J. S. RAO (Indian Institute of Technology, New Delhi, India) and N. S. VYAS (Indian Institute of Technology, Kanpur, India) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-27)

It is demonstrated here that damping is a significant parameter in the stress analysis of turbomachinery blading. Experimentally measured damping envelopes which define the damping ratio as a function of rotational speed and strain amplitude for different modes of vibration are used in the analysis to predict the resonant stresses at three critical speeds. An iterative procedure for utilizing such damping models is presented. The damping model presented here is shown to result in a clear improvement in analytical results compared to previous results using average damping ratio independent of vibratory amplitudes. C.D.

### **A90-23767# A METHODOLOGY PROPOSAL TO DESIGN AND ANALYSE COUNTERROTATING HIGH SPEED PROPELLERS**

D. NICOUUD, J. BROCHET, and M. GOUTINES (SNECMA, Moissy-Cramayel, France) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. refs (ASME PAPER 89-GT-38)

The present CFD methodology for high speed contrarotating propeller design proceeds, first, with the use of the 'throughflow' method, in which a conceptual outer 'case' is used to simulate the unperturbed flow beyond the propellers, and the computational mesh is adapted to the highly swept blade geometry. A quasi-geometrical technique is then used to furnish the bidimensional profiles that account for such structural specifications as chord length, maximum thickness, and root attachment. The three-dimensional transonic flowfield is drawn by an Euler solver on an appropriate domain. O.C.

### **A90-23769# GAS TURBINE COMPRESSOR OPERATING ENVIRONMENT AND MATERIAL EVALUATION**

R. W. HASKELL (General Electric Co., Schenectady, NY) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 13 p. refs (ASME PAPER 89-GT-42)

The reliability and performance of a gas turbine compressor is strongly dependent upon the environment in which it operates, the materials which are used, and the filtration system. Erosion and to a certain extent fouling can be controlled by the filtration system, but corrosion is largely controlled through site and material selection. The factors which determine the corrosivity of a site are humidity, the concentration of acid-forming gases, and the composition of particulates. The interrelationships of these factors are discussed with an aim of reducing their impact on compressor operation. A necessary condition for corrosion is the presence of moisture. The acidity of the moisture results from its interaction with the gases and particulates of the environment. The details of

these interactions which are important to turbine operators are discussed. A considerable amount of corrosion testing of base materials and coatings has been performed and this is reviewed. A table is presented for selection of compressor materials based on the nature of the site environment and the type of compressor filtration.

Author

#### A90-23791#

##### APPLICATION OF RECESS VANED CASING TREATMENT TO AXIAL FLOW FANS

A. R. AZIMIAN, R. L. ELDER, and A. B. MCKENZIE (Cranfield Institute of Technology, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. refs

(ASME PAPER 89-GT-68)

The effect of applying a vaned recessed casing treatment to a single stage axial flow fan has been investigated. The influence of the axial position of the recess relative to the rotor leading edge and other geometrical modifications of the vane passage have been examined. Significant improvements in stall margin were observed without (in some builds) loss in peak efficiency. Slow and fast frequency response yawmeter probes have been used in the study to examine both the steady flow conditions and the unsteady flow caused by rotating stall.

Author

#### A90-23810#

##### EXPERIMENTAL EXAMINATION OF THE AEROTHERMAL PERFORMANCE OF A GAS TURBINE ENGINE TEST FACILITY

E. E. COOPER and C. A. KODRES (U.S. Navy, Naval Civil Engineering Laboratory, Port Hueneme, CA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p.

(ASME PAPER 89-GT-94)

A USN standard jet engine test cell was experimentally examined to determine aerodynamic and thermodynamic characteristics. The data include gas pressures and temperatures measured at both the test cell intakes and exhaust from which velocities were calculated and, subsequently, mass flow rates were calculated and compared. The highest test cell wall temperature recorded was about 300 C reached during A/B testing of a TF30 engine. The vacuum drawn within the facility was within structural limits, reaching a minimum of only 2.5 cm of water. Airflow approaching the engine inlet was always steady and free of eddies or recirculation. Recommendations and conclusions are drawn, indicating that the aerothermal data acquired during future acceptance tests should be used as part of the acceptance inspection of each new test cell, as well as for continued improvement of mathematical modeling, and for better understanding of the principles governing flow in the test cells.

R.E.P.

#### A90-23811#

##### VIBRATION ANALYSIS FOR IMMEDIATE ASSESSMENT OF BATTLE-DAMAGED GAS TURBINE ENGINES

ROBERT H. BADGLEY (Expert Systems, Inc., Reston, VA) and WAYNE A. SHADE (U.S. Navy, Naval Air Propulsion Center, Trenton, NJ) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p.

(ASME PAPER 89-GT-96)

A procedure is needed at the operational unit level to immediately assess the exact nature and extent of engine damage, as well as rapid (perhaps nonstandard) engine repair procedures, for use at forward locations. Such repairs can include reblading of compressors and turbines, replacement of cracked or broken gear cases or gears, and replacement or repair of accessories. Performance indicators, gas path and oil debris quantity and size, and vibration levels can help identify the location and extent of damage. Four damage modes of primary interest to the engine battle damage assessor are noted: (1) changes to the unbalance distributions, (2) changes to gear tooth surfaces, (3) changes to bearing races and/or rolling elements, and (4) loss of sealing. The data obtained indicate that tests on a battle-damaged aircraft

engine can be carried out with two or three accelerometers, requiring only a few minutes for each engine.

R.E.P.

#### A90-23820#

##### DUAL PRESSURE RATIO COMPRESSOR

CHARLES J. PAINE (Allied-Signal Aerospace Co., Garrett Auxiliary Power Div., Phoenix, AZ) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. refs

(ASME PAPER 89-GT-121)

The dual pressure ratio centrifugal compressor was conceived and developed as part of an advanced auxiliary power unit (APU) program to provide relative low pressure bleed flow and high pressure turbine flow from a single stage centrifugal compressor. Test results showed that the compressor efficiency and pressure ratio were predicted for the flow split off to the turbine. The bleed flow side vaneless diffuser experienced a strong flow separation. Mechanical problems were encountered with the flow splitter shroud.

Author

#### A90-23852#

##### THE DESIGN AND TEST OF A TWO STAGE TRANSONIC AXIAL FLOW COMPRESSOR

R. G. WELLS, G. BATY, F. CARCHEDI, and G. R. WOOD (Ruston Gas Turbines, Ltd., Gas Turbine Engineering Div., Lincoln, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs

(ASME PAPER 89-GT-164)

The design of the transonic stages, which form the front two stages of a multi stage compressor, is described. The first stage tip Mach No. is 1.1. The test program to evaluate the performance of the two stages is outlined and detailed results of the overall and stage performance are presented. Details of the flow field from traverse measurements and the over tip shock structure obtained from high response pressure transducers are compared with predictions. Strain Gauge results taken from the rotating blades are also presented.

Author

#### A90-23853#

##### A NUMERICAL THREE-DIMENSIONAL THERMAL STRESS ANALYSIS FOR COOLED BLADES

J. SRINIVASAN, R. PADMANABHAN (Gas Turbine Research Establishment, Bangalore, India), and R. M. S. GOWDA (Indian Institute of Technology, Madras, India) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 4 p. refs

(ASME PAPER 89-GT-168)

A thermal stress analysis is performed for a plane blade profile taking the form of a second-degree surface with constant curvature. The general second-degree polynomial allows all the six static equilibrium equations to be considered in evaluating the strained surface. The three-dimensional state of stress is determined by considering the lateral deformation of the blade profile into account. A numerical procedure is adopted to solve the nonlinear simultaneous equations arising due to the self-equilibrating thermal stress system.

C.D.

#### A90-23854#

##### A COMPARISON BETWEEN ENGINE TEST RESULTS AND DESIGN PREDICTIONS OF TURBINE BLADE COOLING PERFORMANCE

J. M. HANNIS and M. K. D. SMITH (Ruston Gas Turbines, Ltd., Gas Turbine Engineering Div., Lincoln, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs

(ASME PAPER 89-GT-169)

Differences between engine test data, static cascade rig data, and design predictions are compared for several different cooling configurations of two subsonic airfoil cool turbine blades under engine conditions and their design predictions. Reasons for differences are identified and cross-referenced to recently reported studies. Empirical evidence obtained from engine tests is also adduced.

C.D.

## A90-23871#

### REYNOLDS NUMBER EFFECTS ON THE PERFORMANCE OF A TURBOFAN ENGINE

MASAO KOZU (Japan Defence Agency, Technical Research and Development Institute, Tokyo) and SATOSHI YASHIMA (Ishikawajima-Harima Heavy Industries Co., Ltd, Tokyo, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-199)

Reynolds number effects on the matching performance of a small twin-spool turbofan engine were investigated through altitude tests on the F3-30 engine which was developed to power the T-4 intermediate trainer. Analyzing the test results made it clear that the change of the aerodynamic characteristics of the low pressure turbine due to Reynolds number effects is as significant as those of fan and compressor, and it caused the difference between the predicted and measured engine performance at high altitudes. Correlation factors on the Reynolds number for each of the component characteristics (pressure ratio, airflow and efficiency of fan and compressor, and gas flow and efficiency of low pressure turbine) were obtained, and simulation of the engine performance using these factors coincided well with the test data which were obtained from the altitude tests of the F3-30. Author

## A90-23873#

### AXIAL FLOW COMPRESSOR DESIGN OPTIMIZATION. I - PITCHLINE ANALYSIS AND MULTIVARIABLE OBJECTIVE FUNCTION INFLUENCE

ARISTIDE MASSARDO and ANTONIO SATTA (Genova, Università, Genova, Italy) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Research supported by MPI. refs (Contract CNR-87,02280,59) (ASME PAPER 89-GT-201)

The design of an axial flow compressor stage has been formulated as a nonlinear mathematical programming problem with the objective of minimizing the aerodynamic losses, and the weight of the stage while, maximizing the compressor stall margin. Aerodynamic as well as mechanical constraints are considered in the problem formulation. A method of evaluating the objective function and constraints of the problem with a pitchline analysis is presented. The optimization problem is solved by using the penalty function method in which the Davidon-Fletcher-Powell variable metric minimization technique is employed. Designs involving the optimization of efficiency, weight of the stage, and stall margin are presented and the results discussed with particular reference to a multivariable objective function. Author

## A90-23874#

### AXIAL FLOW COMPRESSOR DESIGN OPTIMIZATION. II - THROUGH-FLOW ANALYSIS

ARISTIDE MASSARDO, ANTONIO SATTA, and MARTINO MARINI (Genova, Università, Genova, Italy) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Research supported by MPI. refs (Contract CNR-87,02280,59) (ASME PAPER 89-GT-202)

A new technique is presented for the design optimization of an axial-flow compressor stage. The procedure allows for optimization of the complete radial distribution of the geometry since the variables, chosen to represent the three-dimensional geometry of the stage, are coefficients of suitable polynomials. Evaluation of the objective function is obtained with a through-flow type calculation, which has acceptable speed and stability qualities. Some examples are given of the possibility to use the procedure both for redesign and for the complete design of axial-flow compressor stages. Author

## A90-23884#

### ULTRA HIGH BYPASS (UHB) ENGINE CRITICAL COMPONENT TECHNOLOGY

THOMAS G. CLOFT and PATRICIA L. MULDOON (United Technologies Corp., Pratt and Whitney Group, East Hartford, CT)

ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs (ASME PAPER 89-GT-229)

The Counter-Rotation Propfan (CRP) and Advanced Ducted Prop (ADP) ultrahigh bypass (UHB) engine configurations are presently studied with a view to their comparative thermodynamic cycle features, the identification of their critical component technologies, and their current technology development status within the R&D organization of a major U.S. aircraft engine manufacturer. Significant UHB development program achievements have been made to date concerning CRP blade aerodynamic performance, acoustics, and structural design, as well as in ADP nacelle aerodynamic performance, thrust-reversal apparatus, and speed-reduction gearbox design. O.C.

## A90-23886#

### BRAZE REPAIR OF MA754 AERO GAS TURBINE ENGINE NOZZLES

J. E. ELDER, R. THAMBURAJ, and P. C. PATNAIK (Hawker Siddeley Canada, Inc., Orenda Div., Mississauga) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 13 p. Research supported by DND. refs (ASME PAPER 89-GT-235)

An experimental program aimed at developing a braze repair procedure for healing cracks in MA754 HPT nozzles is described. Thirteen different braze compositions, using two different brazing times and gap widths, are evaluated. Experimental results are described detailing the microstructure, degree of oxide agglomeration, and porosity in the region of the brazed joints. The feasibility of applying a braze repair procedure to the nozzle component is discussed. Author

## A90-23888#

### EXPERIMENTAL INVESTIGATION OF SUPERSONIC TURBINE PERFORMANCE

JOHN W. KURZROCK (Sundstrand Corp., Sundstrand Advanced Technology Group, Rockford, IL) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. Research supported by Sundstrand Corp. refs (ASME PAPER 89-GT-238)

This paper presents the performance obtained from testing single-stage, full-admission, axial supersonic turbine configurations. A matrix of four nozzle and two rotor blade configurations was evaluated. Turbine pressure ratios were varied from 33 to 140 for velocity ratios of 0.2 to 0.5. The test results indicate that constant-channel width and variable-channel width rotor blading give comparable performance. Optimal nozzle and blade configurations yielded turbine efficiencies of 77 percent. Author

A90-23890\*# National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

### ADVANCED CORE TECHNOLOGY - KEY TO SUBSONIC PROPULSION BENEFITS

ARTHUR J. GLASSMAN, CHRISTOPHER A. SNYDER, and GERALD KNIP, JR. (NASA, Lewis Research Center, Cleveland, OH) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Previously announced in STAR as N89-14237. (ASME PAPER 89-GT-241)

A study was conducted to identify the potential performance benefits and key technology drivers associated with advanced cores for subsonic high bypass turbofan engines. Investigated first were the individual sensitivities of varying compressor efficiency, pressure ratio and bleed (turbine cooling); combustor pressure recovery; and turbine efficiency and inlet temperature on thermal efficiency and core specific power output. Then, engine cycle and mission performance benefits were determined for systems incorporating all potentially achievable technology advancements. The individual thermodynamic sensitivities are shown over a range of turbine temperatures (at cruise) from 2900 to 3500 R and for both constant (current technology) and optimum (maximum thermal efficiency) overall pressure ratios. It is seen that no single parameter alone

will provide a large increase in core thermal efficiency, which is the thermodynamic parameter of most concern for transport propulsion. However, when all potentially achievable advancements are considered, there occurs a synergism that produces significant cycle and mission performance benefits. The nature of these benefits are presented along with the technology challenges.

Author

#### A90-23892#

##### ENGINEERING DESIGN OF TOUGH CERAMIC MATRIX COMPOSITES FOR TURBINE COMPONENTS

T. M. TAN, CHRISTOPHER M. PASTORE, and FRANK K. KO (Drexel University, Philadelphia, PA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs  
(ASME PAPER 89-GT-294)

Material design concepts are presented for the toughening of turbine blade ceramic-matrix components, using a fabric-geometry model (FGM) to establish a communication link between structural engineering and material-definition disciplines. The FGM is used to translate the three-dimensional fiber architecture's contribution to material mechanical properties into a stiffness matrix for FEM structural analysis. The feedback obtained from this structural analysis allows the design methodology to screen such reinforcement materials for composite turbine-blading components as SiC in a lithium-aluminum-silica glass matrix. O.C.

#### A90-23893#

##### AN OFF-DESIGN LOSS AND DEVIATION PREDICTION STUDY FOR TRANSONIC AXIAL COMPRESSORS

M. CETIN, A. S. UCER (Middle East Technical University, Ankara, Turkey), CH. HIRSCH (Brussel, Vrije Universiteit, Brussels, Belgium), and G. K. SEROVY (Iowa State University of Science and Technology, Ames) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs  
(ASME PAPER 89-GT-324)

A study on the design and off-design loss and deviation correlations was performed in which transonic compressor test data of 1970s was used. Losses are considered as a whole and expressed by a total pressure loss coefficient with design and off-design parts identified separately. A modified version of NASA-2D minimum loss incidence correlation is proposed for DCA and MCA blades. Koch and Smith design loss correlation was found to be most satisfactory. For DCA and MCA blade profiles new off-design loss correlations were formulated. A correction is proposed to the Carter's design deviation angle prediction method. For off-design deviation prediction Creveling's correlation is easy to apply and gives most consistent and successful results.

Author

#### A90-23896\*#

##### BLADE MISTUNING COUPLED WITH SHAFT FLEXIBILITY EFFECTS IN ROTOR AEROELASTICITY

NAIM KHADER (Jordan University of Science and Technology, Irbid) and ROBERT G. LOEWY (Rensselaer Polytechnic Institute, Troy, NY) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs  
(Contract NAG3-37)  
(ASME PAPER 89-GT-330)

The effect of bladed-disk polar dissymmetry, resulting from variations in mass from one blade to another, on aeroelastic stability boundaries for a fan stage is presented. In addition to both in-plane and out-of-plane deformations of the bladed-disk, bending of the supporting shaft in two planes is considered, and the resulting Coriolis forces and gyroscopic moments are included in the analysis. A quasi-steady aerodynamics approach is combined with the Lagrangian method to develop the governing equations of motion for the flexible bladed-disk-shaft assembly. Calculations are performed for an actual fan stage. Author

#### A90-24216

##### AN AUTOMATIC SYSTEM FOR THE PROGRAMMED CONTROL OF THE PARAMETERS OF THE VIBRATIONAL AND THERMAL TESTING OF THE BLADES OF GAS TURBINE ENGINES [AVTOMATIZIROVANNAIA SISTEMA PROGRAMMNOGO REGULIROVANIIA PARAMETROV VIBRATSIONNYKH I TERMICHESKIKH ISPYTANII LOPATOK GTD /ASPR VTI/]

V. T. TROSHCHENKO, V. S. KOSTENKO, A. P. VOLOSHCHENKO, IU. K. ZAKHAROV, V. A. ROVKOV (AN USSR, Institut Problem Prochnosti, Kiev, Ukrainian SSR) et al. Problemy Prochnosti (ISSN 0556-171X), Jan. 1990, p. 102-105. In Russian. Copyright

The general design, principal components, and operation of an automatic system for the programmed control of the parameters of the vibrational and thermal testing of gas turbine blades are briefly described. The system, which is designed for the control of electrodynamic vibrational test stands and heating devices of various kinds, makes it possible to estimate the fatigue life and the limiting state of turbine blades under conditions of varying vibrational and thermal loads over a wide blade frequency range (10-10,000 Hz). V.L.

#### A90-25036\*#

##### National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

##### LOW NO(X) POTENTIAL OF GAS TURBINE ENGINES

ROBERT R. TACINA (NASA, Lewis Research Center, Cleveland, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 19 p. refs  
(AIAA PAPER 90-0550) Copyright

Nitrogen oxide levels of low gas turbine engine emissions are correlated in this paper. The predictions of NO(x) emissions are based on a review of the literature of previous low NO(x) combustor programs and analytical chemical kinetic calculations. Concepts included in the literature review consisted of Lean-Pre-mixed-Prevaporized (LPP), Rich Burn/Quick Quench/Lean/Burn (RQL), and Direct Injection. The NO(x) emissions were found to be an exponential function of adiabatic combustion temperature over a wide range of inlet temperatures, pressures and (lean) fuel-air ratios. It is stated that the low NO(x) potential of LPP is offset by the operational disadvantages of its narrow stability limits and its susceptibility to autoignition/ flashback. The RQL and the Direct Injection concepts have the advantage of wider stability limits comparable to conventional combustors. Results were obtained primarily with gaseous fuels and it is noted that the challenge will be to produce the same low levels of NO(x) with liquid fuels. R.E.P.

#### N90-16759#

##### Oxford Univ. (England). Dept. of Engineering Sciences.

##### WAKE INTERACTION EFFECTS ON THE TRANSITION

##### PROCESS ON TURBINE BLADES Final Report, 1 Sep. 1985 - 31 Dec. 1988

R. W. AINSWORTH and J. E. LAGRAFF (Syracuse Univ., NY.) Sep. 1989 16 p  
(Contract AF-AFOSR-0295-85; AF PROJ. 2307)  
(AD-A214492; AFOSR-89-1342TR) Avail: NTIS HC A03/MF A01 CSDL 20/4

The unsteady behavior of a 2-D gas turbine rotor blade boundary layer was observed using wide bandwidth surface heat transfer thin film gauges. The tests were conducted in a compression heated short duration wind tunnel cascade at realistic gas turbine aero/thermo-dynamic conditions. Wake passage effects were generated using a rotating set of upstream bars. The unsteadiness of the wake and shock interactions were observed through the effects on temporally and spatially accurate heat transfer measurements. GRA

#### N90-16762#

##### Army Aviation Systems Command, Saint Louis, MO.

##### USING GOAL PROGRAMMING TO DETERMINE THE OPTIMAL ENGINE MIX FOR UH-1 HELICOPTERS



KIMBERLY S. SCHENKEN 8 Aug. 1989 49 p  
(AD-A214893) Avail: NTIS HC A03/MF A01 CSCL 12/4

This paper presents a methodology for using Sequential Linear Goal Programming to determine the optimal decision when decision makers have conflicting goals. An example is presented to demonstrate the technique. The demonstration problem is whether the UH-1 Helicopter's engine should be rebuilt or replaced with a modern engine. The Army has several conflicting criteria to consider in this decision. For example, they want to minimize both investment cost and operating and support costs, and maximize the performance of the weapon system. This paper illustrates how goal programming is useful in highlighting trade-offs in decisions, and in demonstrating to decision makers the effect of postponing cost reducing improvements to weapon systems. The disadvantage of goal programming is that the formulation of the problem is complex and many problems may require too large a problem to be feasible. GRA

**N90-16766#** Institut Franco-Allemand de Recherches, Saint-Louis (France).

## EXPERIMENTAL STUDY OF VELOCITY FIELDS AND TURBULENCE IN A TURBOJET ENGINE [ETUDE EXPERIMENTALE DES CHAMPS DE VITESSE ET DE TURBULENCE D'UN JET DE TURBOREACTEUR]

H. J. SCHAEFER 29 Sep. 1988 18 p In FRENCH Presented at Journees Francaises d'Anemometrie Laser, Marseille, France, 21-23 Sep. 1988 Original contains color illustrations (ISL-CO-231/88; ETN-90-96090) Avail: NTIS HC A03/MF A01

Laser velocimetry is used to measure the velocity and turbulence profiles in a hot jet from the Microturbo TRS 18 turbo reactor. The ejection velocity is between 265 and 520 m/s and the temperatures are 820 to 960 K. Signal treatment is made with equipment developed for high velocity flow data processing. TiO<sub>2</sub> is employed as a tracer. The results are in good agreement with a theoretical model previously developed. ESA

**N90-16817#** Societe Nationale d'Etude et de Construction de Moteurs d'Aviation, Corbeil (France).

## PROGRESS IN AIRBREATHING COMBINED ENGINES FOR FUTURE EUROPEAN LAUNCHER

MICHEL DOUBLIER, P. RAMETTE, and D. SCHERRER (Office National d'Etudes et de Recherches Aerospatiales, Paris, France) In ESA, Progress in Space Transportation p 279-285 Aug. 1989

Copyright Avail: NTIS HC A22/MF A03

An overview of research in the area of combined engine cycles is presented. The usefulness of such air breathing engines in developing a hypersonic winged launcher is outlined. Information on turbo-rocket, rocket-ramjet and turbofan-ramjet rocket systems is presented. Engine/vehicle integration problems are addressed, and critical technology areas are identified. It is concluded that the best engine system choice cannot yet be made. The technology needed for a successful airbreathing combined engine launcher will require a ten year period for development. ESA

**N90-16818#** Messerschmitt-Boelkow-Blohm G.m.b.H., Munich (Germany, F.R.).

## SAENGER PROPULSION SYSTEM OPTIONS

NORBERT VOSS and MARTIN ALBERS (Motoren- und Turbinen-Union Muenchen G.m.b.H., Germany, F.R.) In ESA, Progress in Space Transportation p 287-292 Aug. 1989 Copyright Avail: NTIS HC A22/MF A03

A general survey of concept definition and performance characteristics involved in choosing a propulsion system for the Saenger launcher is presented. Initial concept studies considered a parallel turbojet-ramjet system for the first stage. Alternative concepts such as tandem-turbo-ramjet, with and without intercooling, and a turboexpander-ramjet with and without precombustion are investigated. Engine integration and propulsion system size, dependent on engine configuration, are discussed. A survey of currently available and future required test facilities is presented. ESA

**N90-16819#** Rolls-Royce Ltd., Bristol (England).

## PARAMETRIC ASSESSMENT OF PROPULSION SYSTEM MASS FOR AIRBREATHING LAUNCHER CONFIGURATIONS

F. A. HEWITT and RAINER R. SCHWAB In ESA, Progress in Space Transportation p 293-298 Aug. 1989 Sponsored in part by ESA

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Sensitivity of power plant mass to such variables as vehicle thrust requirements, precompression surface incidence, intake and nozzle designs and turbomachinery design constraints is described. A turbo-ramjet power plant propelling the first stage of a two-stage-to-orbit launcher is studied. The engine is behind a rectangular ramp intake with the reheat system operating as a ramjet burner for flight beyond Mach 3. Aspects of overall vehicle performance are described and the influence of mission definition on power plant optimization is discussed. ESA

**N90-17634#** Cambridge Univ. (England). Dept. of Engineering.

## A METHOD FOR THE PREDICTION OF SUPERSONIC COMPRESSOR BLADE PERFORMANCE

C. FREEMAN (Rolls-Royce Ltd., Derby, England) and N. A. CUMPTSTY 1989 35 p Presented at the 34th ASME International Gas Turbine and Aeroengine Congress and Exposition (CUED/A-TURBO/TR-126; REPT-89-GT-326; ISSN-0309-6521) Avail: NTIS HC A03/MF A01

A simple model is used to calculate the flow in compressor blades with supersonic relative inlet flow. The method addresses the common irreversible deceleration and compression which takes place when a shock stands ahead of the blade leading edge. It does not attempt to describe the process when inverse camber in the forward part is used to decelerate the flow before the shock. The one-dimensional model utilizes the conservation of stagnation enthalpy, mass flow and momentum in the inlet region. The momentum equation is applied in the direction parallel to the blade surface at inlet and one of the fundamental simplification adopted is that the projected area of the blades gives such a small force in this direction that a very simple approximation for it suffices. The model is able to predict the loss creation in the inlet region. The level of calculated loss agree well with measured values when the Mach numbers are sufficiently high for the inlet loss to dominate. Furthermore, the correct trends of loss with incidence and blade speed are predicted. The pressure rise and flow can also be predicted when the correct deviation and meridional streamtube convergence are given. The method predicts trends usually seen in measurements: the narrowing of the useful operating range between choke and flow instability (surge) as blade speed is increased and a steepening of the surge line at the higher speeds. Author

**N90-17635#** Sverdrup Technology, Inc., Cleveland, OH.

## VISCOUS THREE-DIMENSIONAL ANALYSES FOR NOZZLES FOR HYPERSONIC PROPULSION Final Report

G. J. HARLOFF, D. R. REDDY, and H. T. LAI Jan. 1990 25 p Proposed for presentation at the AGARD Symposium on Combined Cycle Propulsion for Hypersonic Application, Madrid, Spain, 21-25 May 1990

(Contract NAS3-24105; NAS3-25266) (NASA-CR-185197; E-5267; NAS 1.26:185197) Avail: NTIS HC A03/MF A01 CSCL 21/5

A Navier-Stokes computer code was validated using a number of two- and three-dimensional configurations for both laminar and turbulent flows. The validation data covers a range of freestream Mach numbers from 3 to 14, includes wall pressures, velocity profiles, and skin friction. Nozzle flow fields computed for a generic scramjet nozzle from Mach 3 to 20, wall pressures, wall skin friction values, heat transfer values, and overall performance are presented. In addition, three-dimensional solutions obtained for two asymmetric, single expansion ramp nozzles at a pressure ratio of 10 consists of the internal expansion region in the converging/diverging sections and the external supersonic exhaust in a quiescent ambient environment. The fundamental characteristics that were captured successfully include expansion fans; Mach wave reflections; mixing layers; and nonsymmetrical,

multiple inviscid cell, supersonic exhausts. Comparison with experimental data for wall pressure distributions at the center planes shows good agreement. Author

**N90-17636\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**LOW NO(X) POTENTIAL OF GAS TURBINE ENGINES**

ROBERT R. TACINA 1990 20 p Presented at the 28th Aerospace Sciences Meeting, Reno, NV, 8-11 Jan. 1990; sponsored by AIAA

(NASA-TM-102452; E-5237; NAS 1.15:102452; AIAA-90-0550)

Avail: NTIS HC A03/MF A01 CSCL 21/5

The purpose is to correlate emission levels of gas turbine engines. The predictions of NO(x) emissions are based on a review of the literature of previous low NO(x) combustor programs and analytical chemical kinetic calculations. Concepts included in the literature review consisted of lean-premixed-prevaporized (LPP), rich burn/quick quench/lean burn (RQL), and direct injection. The NO(x) emissions were found to be an exponential function of adiabatic combustion temperature over a wide range of inlet temperatures, pressures and (lean) fuel-air ratios. A simple correlation of NO(x) formation with time was not found. The LPP and direct injection (using gaseous fuels) concepts have the lowest NO(x) emissions of the three concepts. The RQL data has higher values of NO(x) than the LPP concept, probably due to the stoichiometric temperatures and NO(x) production that occur during the quench step. Improvements in the quick quench step could reduce the NO(x) emissions to the LPP levels. The low NO(x) potential of LPP is offset by the operational disadvantages of its narrow stability limits and its susceptibility to autoignition/flashback. The Rich-Burn/Quick-Quench/Lean-Burn (RQL) and the direct injection concepts have the advantage of wider stability limits comparable to conventional combustors. Author

**N90-17638\*#** General Electric Co., Cincinnati, OH. Aircraft Engine Business Group.

**ALTITUDE TESTING OF THE 2D V-STOL ADEN DEMONSTRATOR ON AN F404 ENGINE Final Report**

J. T. BLOZY Feb. 1985 110 p

(Contract NAS3-23042)

(NASA-CR-174824; NAS 1.26:174824) Avail: NTIS HC A06/MF A01 CSCL 21/5

The Augmented Deflector Exhaust Nozzle (ADEN) exhaust system was tested in the PSL-3 altitude chamber at the NASA Lewis Research Center in order to evaluate aerodynamic performance, cooling-system effectiveness, and mechanical operation at flight-type conditions. The ADEN, a flight-weight, two-dimensional, thrust-vectoring nozzle, was successfully tested on the F404 engine using a remote engine control system for automatic or manual setting of the throat-area control and available fan air for the nozzle internal cooling system. Throughout the test, the ADEN performed with no adverse effects on the engine or augmentor operation. R.J.F.

## 08

## AIRCRAFT STABILITY AND CONTROL

Includes aircraft handling qualities; piloting; flight controls; and autopilots.

**A90-23979**

**AIRCRAFT PROGRAM MOTION ALONG A PREDETERMINED TRAJECTORY. I - MATHEMATICAL MODELLING**

W. BLAJER and J. PARCZEWSKI (Radom, Politechnika, Poland) Aeronautical Journal (ISSN 0001-9240), vol. 94, Jan. 1990, p. 17-23. refs

Copyright

A mathematical model is presented of the aircraft program flight along a predetermined trajectory, with or without a specified

speed history. Moreover, the aircraft is constrained to coordinated turns, which implies zero value of sideslip angle. The final equations of program motion are derived as a set of differential/algebraic equations. The aircraft control input ensuring the exact realization of program constraints results from the transient dynamic solution of the equations of program motion. A simple numerical illustration is included. Author

**A90-24002#**

**CONCISE DESIGN OF AIRCRAFT LONGITUDINAL MODEL REFERENCE ADAPTIVE COMMAND AUGMENTATION SYSTEM**

SHUNDA XIAO and LINING YU (Northwestern Polytechnical University, Xian, People's Republic of China) Northwestern Polytechnical University, Journal (ISSN 1000-2758), vol. 8, Jan. 1990, p. 17-26. In Chinese, with abstract in English. refs

A concise algorithm for a model reference adaptive control system is presented which extends the concept of 'elimination of real positivity condition' proposed by Landau (1978) to the case of the adaptive controller. Using this design procedure, the determination of the compensator coefficient becomes significantly simpler, and the dimension of the algorithm can be considerably reduced so that the computation time significantly decreases. The proposed algorithm is applied to an adaptive longitudinal command augmentation system. Simulation results show that the tuning procedure is rather easy. The system is also robust for unmodeled long period mode. C.D.

**A90-24147**

**A METHOD FOR DETERMINING AILERON EFFICIENCY AND CRITICAL REVERSAL AND DIVERGENCE RATES AT TRANSONIC VELOCITIES [METOD OPREDELENIIA EFFEKTIVNOSTI ELERONA I KRITICHESKIKH SKOROSTEI REVERSA I DIVERGENTSII PRI TRANSZVUKOVYKH SKOROSTIAXH]**

P. D. NUSHTAEV and I. U. P. NUSHTAEV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 113-121. In Russian. refs

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Results of numerical and experimental studies of aileron efficiency at transonic velocities are reported. The critical reversal and divergence rates of a wing are estimated on the basis of a wind tunnel experiment and calculations based on linear and nonlinear theories. V.L.

**A90-24164**

**FLUTTER AND AILERON REVERSAL SAFETY FACTORS [O KOEFFITSIENTAKH 'ZAPASA PO FLATTERU' I 'ZAPASA PO REVERSU']**

I. A. M. PARKHOMOVSKII and L. S. POPOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 94-102. In Russian.

Copyright

Considerations are presented which govern the assignment of safety factors when solving the problem of aircraft safety with respect to flutter and aileron reversal. The approach used here is based on ensuring a sufficiently large value of the vibration decrement. In practice this approach is implemented on the basis of safety factors in terms of velocity and parameters. V.L.

**A90-24171**

**CALCULATION OF THE VIBRATIONS OF AIRCRAFT WITH ELASTIC SUSPENDED LOADS [RASCHET KOLEBANI LETATEL'NOGO APPARATA S UPRUGIMI PODVESNYMI GRUZAMI]**

V. A. MOSUNOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 130-134. In Russian.

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A method is described for the coupling of two elastic systems in order to calculate the natural vibrations of aircraft with external suspensions. To illustrate the possibilities of the approach proposed here, calculations are carried out for two parallel homogeneous elastic beams hinged together at the ends. V.L.



**A90-24281**

## **PAY-OFFS AND PITFALLS OF FLY-BY-WIRE**

B. R. A. BURNS and J. C. GIBSON (British Aerospace /Military Aircraft/, Ltd, Preston, England) *Interavia* (ISSN 0020-5168), vol. 44, Dec. 1989, p. 1208-1211.

Copyright

Flight control systems in the electronic age have helped to bring about the canard and other exotic layouts, giving fighters new maneuverability and new controllability. With full-time FBW and with motion sensors in the loop at all times, natural airframe stability is no longer essential. Artificial stability particularly benefits the tailless aircraft, previously suffering severe trimmed-lift loss and high trim drag at high lift, to the detriment of combat performance. Perhaps the most remarkable result is the emergence of the unstable canard as a favored layout for air superiority fighters, exemplified by the EAP and EFA, the Rafale, the Gripen, and the Lavi. Advantages of the unstable canard over the stable canard are described. Apart from the direct performance benefits of full time FBW, the other major advantage has been the promise of 'carefree maneuvering'. By limiting the pilot's ability to apply severe control inputs as the airframe limits are approached, the aircraft can be prevented from entering a spin or being overstressed. In effect, full time FBW control can erect safety barriers where previously there were marginal safety areas. Near universal adoption of digital computing in second generation FBW control systems has become standard, concluding that FBW is now approaching maturity. R.E.P.

**A90-24284#**

## **THE INFLUENCE OF SELECTED GEOMETRICAL AND MASS PARAMETERS ON THE STRUCTURAL DYNAMICS OF AN AIRCRAFT WITH A VARIABLE-GEOMETRY AIRFOIL [WPLYW WYBRANYCH PARAMETROW GEOMETRYCZNYCH I MASOWYCH NA DYNAMIKE KONSTRUKCJI SAMOLOTU Z PLATEM O ZMIENNEJ GEOMETRII]**

JAN BLASZCZYK (Wojskowa Akademia Techniczna, Warsaw, Poland) *Technika Lotnicza i Astronautyczna* (ISSN 0040-1145), vol. 44, June 1989, p. 5-10, 15, 16. In Polish. refs

The paper presents the results of a numerical analysis of the symmetric free vibrations of an aircraft with a variable-geometry airfoil. An analysis is made of how certain geometrical and mass parameters affect the frequency spectrum of the system. Results are presented for a fighter aircraft. B.J.

**A90-24338**

## **THE PERFORMANCE AND LONGITUDINAL STABILITY AND CONTROL OF LARGE RECEIVER AIRCRAFT DURING AIR TO AIR REFUELING**

A. W. BLOY and V. TROCHALIDIS (Manchester, Victoria University, England) *Aeronautical Journal* (ISSN 0001-9240), vol. 93, Dec. 1989, p. 367-378. Research supported by the Ministry of Defence and SERC. refs

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The aerodynamic interference between typical tanker and large receiver aircraft during air-to-air refueling was modelled using a simple horseshoe vortex representation of the tanker wake while the aerodynamic forces and moments acting on the receiver were calculated using the vortex lattice method. The aerodynamic model is used to obtain drag predictions and the stability and control characteristics of two large receiver aircraft, with particular attention given to the high T-tail receiver. The T-tail receiver aircraft exhibits static stability with respect to vertical displacement from the normal refueling position although it is dynamically unstable. Moving the center of gravity forward improves the stability while increasing the aircraft speed has a detrimental effect on stability. The frequency of the pitch oscillation appears to be related to the frequency of the short period oscillation which is similar to that in normal flight. R.E.P.

**A90-25102**

## **A UNIFIED APPROACH TO THE OVERALL BODY MOTION STABILITY AND FLUTTER CHARACTERISTICS OF ELASTIC AIRCRAFT**

QIANGANG LIU and YONGNIAN YANG (Northwestern Polytechnical University, Xian, People's Republic of China) *Chinese Journal of Aeronautics* (ISSN 1000-9361), vol. 2, Nov. 1989, p. 216-224. refs

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The Green's function method for fully unsteady aerodynamics around three-dimensional bodies is outlined. This method is used to evaluate the unsteady aerodynamic loads and derivatives of a nonrigid aircraft structure. The equations of motion are also presented, and a unified method is employed to analyze the dynamic stability and the flutter characteristics of a nonrigid rigid aircraft structure. Numerical examples show that the results of the present method are in good agreement with the results of other methods. R.E.P.

**A90-25168#**

## **AN ANALYSIS OF FEEL SYSTEM EFFECTS ON LATERAL FLYING QUALITIES**

ERIC POTSDAM and JOHN HODGKINSON (Douglas Aircraft Co., Long Beach, CA) *AIAA, Aerospace Engineering Conference and Show*, Los Angeles, CA, Feb. 13-15, 1990. 9 p. refs (AIAA PAPER 90-1824)

Time delays have become a major hurdle in the effort to achieve good aircraft flying qualities. A source of time delay which, up to now, has received limited attention is the cockpit feel system. Conclusions from a recent NT-33 flying qualities investigation bring into question the relative importance of feel system phase lag characteristics in the overall measure of a higher-order flight control system's time delay. The Cooper-Harper ratings indicate that the pilot may partially compensate for the time delays inherent in a low-frequency feel system so that the degradation in flying qualities is less than expected based solely on dynamics. The issue is examined analytically using pilot modeling techniques. The complex dynamics involved in translating a neural signal into a muscle force and then into a controller position output are formulated as a second-order lag, approximating the overall physical system, plus a time delay. This representation of limb and manipulator dynamics, if adequate, provides insight into how the pilot is able to adapt to a wide range of feel system dynamics. Author

**A90-25186**

## **STATIC AND DYNAMIC LOSS OF STABILITY OF ELEMENTS OF A SUPERSONIC AEROPLANE COVERING - NUMERICAL ANALYSIS**

A. OLEJNIK and P. ZALEWSKI (Wojskowa Akademia Techniczna, Warsaw, Poland) *Journal of Technical Physics* (ISSN 0324-8313), vol. 29, no. 3-4, 1988, p. 349-363.

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The statistical and dynamical analysis method developed by Olejnik (1986) for the surface structure of a supersonic aircraft is presently demonstrated to be straightforwardly implementable on a PC. The analysis modeled the surface structure in terms of rectangular plates bounded by stringers and ribs. Attention is given to the numerical analysis of self-excited vibrations and forced vibrations, and divergent stability loss. O.C.

**A90-25189**

## **DYNAMICS OF SPATIAL MOTION OF AN AEROPLANE AFTER DROP OF LOADS**

Z. DZYGADLO and K. SIBILSKI (Wojskowa Akademia Techniczna, Warsaw, Poland) *Journal of Technical Physics* (ISSN 0324-8313), vol. 29, no. 3-4, 1988, p. 399-415. refs

Copyright

The previously established dynamics of longitudinal motion for a jet-powered aircraft which has been disturbed by the symmetric drop of underslung loads is presently generalized to cases of asymmetric drops of those loads. Attention is given to disturbances occurring in rectilinear and curvilinear symmetric flight in the vertical plane, and in a coordinated turn after asymmetric airdrop. Single and double drops in controlled and uncontrolled motions are covered. The equations of motion of the center-of-mass are written in the air-trajectory reference frame. O.C.

A90-25199

**AIRCRAFT PROGRAM MOTION ALONG A PREDETERMINED TRAJECTORY. II - NUMERICAL SIMULATION WITH APPLICATION OF SPLINE FUNCTIONS TO TRAJECTORY DEFINITIONS**

W. BLAJER (Radom, Wyższa Szkoła Inżynierska, Poland)  
Aeronautical Journal (ISSN 0001-9240), vol. 94, Feb. 1990, p. 53-58. refs

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Aspects of numerical simulation of aircraft program flight along a predetermined trajectory are presented. An emphasis is laid on the problem of describing the required trajectory by means of a succession of defined points. A spline function method is used for interpolation and smoothing routines. Some numerical illustrations of aircraft trajectory flight simulation (only planar motion) are demonstrated and discussed. Author

A90-25420

**NONLINEAR EFFECTS IN HELICOPTOR ROTOR FORWARD FLIGHT FORCED RESPONSE**

M. B. MATHEW and R. G. LOEWY (Rensselaer Polytechnic Institute, Troy, NY) Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 1-18. refs

(Contract DAAG29-82-K-0093)

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A method recently developed for analyzing the nonlinear behavior of relatively limber rotor blades is used here to study nonlinear effects in forward flight forced response. It uses the nonrotating, uncoupled natural modes of a flat blade as generalized coordinates to examine the forced response of a YUH-61A blade in forward flight. Fully linear results are first presented and the effects on displacement and bending moments of higher harmonic loads, pretwist and aerodynamic mesh size are discussed. Results of three nonlinear analyses of increasing completeness are then presented: a partially linear analysis, a partially nonlinear analysis, and a fully nonlinear analysis. Differences in results produced by these analysis procedures are found to be substantial in lag bending and torsion response. R.E.P.

A90-25421

**A STUDY OF ROLL RESPONSE REQUIRED IN A LOW ALTITUDE SLALOM TASK**

H.-J. PAUSDER (DLR, Institut fuer Flugmechanik, Brunswick, Federal Republic of Germany) Vertica (ISSN 0360-5450), vol. 14, no. 1, 1990, p. 19-30. refs

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A helicopter in-flight simulation was conducted to investigate the influence of roll sensitivity, roll damping, and roll-to-pitch coupling on the evaluation of handling qualities. The task for the test pilots was to fly a slalom track set up with poles on the ground. The altitude (100 ft) and the airspeed (60 kts) had to be maintained fairly constant. The slalom task represents the roll response demands of an NOE flight. The experiment utilized the variation capability of the DLR B0 105-S3 helicopter equipped with a fly-by-wire control system. The research helicopter, the flight flight-test setup, and the test procedure are described. Results are shown in terms of Cooper-Harper ratings and pilot comments. The results yield the suggestion of a higher level of roll sensitivity and damping in comparison to the current criteria. In addition, approaches for task-performance evaluation are discussed and correlated with the test data. Author

A90-25987#

**IDENTIFICATION OF MODERATELY NONLINEAR FLIGHT MECHANICS SYSTEMS WITH ADDITIVE PROCESS AND MEASUREMENT NOISE**

RAVINDRA V. JATEGAONKAR and ERMIN PLAETSCHKE (DLR, Institut fuer Flugmechanik, Brunswick, Federal Republic of Germany) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 277-285. Research supported by DFG. Previously cited in issue 21, p. 3495, Accession no. A88-50591. refs

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A90-25990#

**RESTRUCTURABLE CONTROL USING PROPORTIONAL-INTEGRAL IMPLICIT MODEL FOLLOWING**

ROBERT F. STENGEL (Princeton University, NJ) and CHIEN Y. HUANG Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 303-309. Previously cited in issue 22, p. 3540, Accession no. A87-50433. refs

(Contract DAAG29-84-K-0048)

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A90-25995#

**UNFOLDING OF DOUBLE-ZERO EIGENVALUE BIFURCATIONS FOR SUPERSONIC FLOW PAST A PITCHING WEDGE**

N. SRI NAMACHCHIVAYA (Illinois, University, Urbana) and H. J. VAN ROESSEL (Alberta, University, Edmonton, Canada) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 343-347. Research supported by NSERC. refs

(Contract AF-AFOSR-88-0233)

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In this paper a complete unfolding of a codimension two bifurcation due to a double-zero eigenvalue of the equations of pitching motion of a double-wedge airfoil is carried out. The critical parameter values along with various parameters related to stiffness derivatives and damping derivatives are tabulated for a thin airfoil for a range of Mach numbers. Both local and global bifurcations of the trivial and nontrivial fixed points and uniqueness of limit cycles are determined. Author

A90-26177\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**TOWARD A HUMAN-CENTERED AIRCRAFT AUTOMATION PHILOSOPHY**

CHARLES E. BILLINGS (NASA, Ames Research Center, Moffett Field, CA) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 1-8. refs

The evolution of automation in civil aircraft is examined in order to discern trends in the respective roles and functions of automation technology and the humans who operate these aircraft. The effects of advances in automation technology on crew reaction is considered and it appears that, though automation may well have decreased the frequency of certain types of human errors in flight, it may also have enabled new categories of human errors, some perhaps less obvious and therefore more serious than those it has alleviated. It is suggested that automation could be designed to keep the pilot closer to the control of the vehicle, while providing an array of information management and aiding functions designed to provide the pilot with data regarding flight replanning, degraded system operation, and the operational status and limits of the aircraft, its systems, and the physical and operational environment. The automation would serve as the pilot's assistant, providing and calculating data, watching for the unexpected, and keeping track of resources and their rate of expenditure. R.E.P.

A90-26189#

**VISUAL INFORMATION FOR SIMULATED LANDING APPROACHES**

GAVAN LINTERN and MICHAEL WALKER (Illinois, University, Savoy) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 122-127. refs

(Contract MDA903-86-C-0169)

Two experienced pilots flew landing approaches in a simulator with a computer-animated visual display different settings of magnification and scene detail. Magnification had strong biasing effects on glideslope control with higher magnifications resulting in lower approaches. Implications for the design of visual scenes and for their calibration are discussed. Author

A90-26222\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**AVOIDING A MANEUVERING AIRCRAFT WITH TCAS**

SHERYL L. CHAPPELL (NASA, Ames Research Center, Moffett Field, CA) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 338-343.

The present investigation was carried out in NASA's Man-Vehicle Systems Research Facility B 727 simulator because of the need for veridical aircraft response. Pilot performance was measured in testing TCAS II after an avoidance maneuver has been initiated. A proposed change to the system will cause the TCAS II to issue a subsequent maneuver. This maneuver may be an increase in climb or descent rate from 1500 to 2500 ft/min, or a change from a climb to a descent or a descent to a climb. Three questions were addressed: (1) can the pilot detect the change in the maneuver advisory, (2) can the pilot respond promptly and accurately to the new advisory, and (3) can the maneuver be performed in the normal operating envelope of the aircraft. The reaction times found in the study suggest that pilots are able to respond within the two seconds targeted by the TCAS logic. The pilot performance data were used to modify the TCAS II logic to reflect actual pilot performance. This will result in a safe and appropriate maneuver selection in the rare instance when the conflicting aircraft maneuvers, and by doing so invalidates the initial maneuver issued by the collision avoidance system. R.E.P.

## **A90-26258\*# Western Aerospace Labs., Inc., Moffett Field, CA. THE BENEFITS AND COSTS OF AUTOMATION IN ADVANCED HELICOPTERS - AN EMPIRICAL STUDY**

MICHAEL R. BORTOLUSSI (Western Aerospace Laboratories, Inc., Moffett Field, CA) and MICHAEL A. VIDULICH (USAF, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 2. Columbus, OH, Ohio State University, 1989, p. 594-599. refs (Contract NCC2-486)

A helicopter simulation was conducted to examine the interaction between voice-activated controls and altitude-hold automation. A single-pilot scout/attack helicopter with conventional controls was simulated with full out-the-window computer-generated imagery. Helicopter pilots performed simulated missions which included hover, cruise and ground attack phases. For half of the flights, voice-activated controls were used instead of manual controls, for two flight tasks (weapon selection and data-burst transmission). Hover performance during data-burst hover improved when voice-activation was used. However, subjective ratings indicated higher workload levels with voice-activation. An altitude-hold automation manipulation was crossed with the voice-activation/manual manipulation. Altitude-hold automation provided two significant benefits: (1) pilots were able to hover with less lateral movement; and (2) pilots reported less workload. However, there was a performance cost associated with the automation. Pilots were significantly slower in responding to unexpected events during hover. Author

## **A90-26820\*# National Aeronautics and Space Administration. Hugh L. Dryden Flight Research Facility, Edwards, CA. AN IN-FLIGHT INTERACTION OF THE X-29A CANARD AND FLIGHT CONTROL SYSTEM**

MICHAEL W. KEHOE, LISA J. BJARKE (NASA, Flight Research Center, Edwards, CA), and EDWARD J. LAURIE (Grumman Aerospace Corp., Bethpage, NY) IN: AIAA Dynamics Specialists Conference, Long Beach, CA, Apr. 5, 6, 1990, Technical Papers. Washington, DC, American Institute of Aeronautics and Astronautics, 1990, p. 469-486. refs (AIAA PAPER 90-1240) Copyright

This paper presents the details of an aeroservoelastic interaction experienced in flight by the X-29A forward-swept-wing aircraft. A 26.5-Hz canard pitch-mode response was aliased by the digital sampling rate in the canard-position feed-back loop of the flight-control system, resulting in a 13.5-Hz signal being commanded to the longitudinal control surfaces. The amplitude of this commanded signal increased as the wear of the canard seals increased, as the feedback path gains were increased, and as the canard aerodynamic loading decreased. The resultant

control-surface deflections were of sufficient amplitude to excite the structure. The flight data presented shows the effect of each component (structural dynamics, aerodynamics, and flight-control system) for this aeroservoelastic interaction. Author

## **N90-16767\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.**

### **RESULTS OF AIRCRAFT OPEN-LOOP TESTS OF AN EXPERIMENTAL MAGNETIC LEADER CABLE SYSTEM FOR GUIDANCE DURING ROLL-OUT AND TURN-OFF**

W. THOMAS BUNDICK, DAVID B. MIDDLETON, and WILLIAM L. POOLE Washington Feb. 1990 40 p (NASA-TM-4135; L-16574; NAS 1.15:4135) Avail: NTIS HC A03/MF A01 CSCL 01/3

An experimental magnetic leader cable (MLC) system designed to measure aircraft lateral displacement from centerline and heading relative to centerline during rollout, turnoff, and taxi was tested at NASA's Wallops Flight Facility using NASA's Transport System Research Vehicle (TSRV), a modified B-737. The MLC system consisted of ground equipment that produced a magnetic field about a wire along runway centerline and airborne equipment that detected the strength and direction of this field and computed displacement and heading. Results of these tests indicate that estimates of aircraft displacement from centerline produced by the magnetic leader cable system using either of the two algorithms appear to be adequate for use by an automatic control system during rollout, turnoff, and taxi. Estimates of heading, however, are not sufficiently accurate for use, probably because of distortion of the magnetic field by the metal aircraft. Author

## **N90-16768\*# Boeing Commercial Airplane Co., Seattle, WA.**

### **DESIGN OF INTEGRATED PITCH AXIS FOR AUTOPILOT/AUTO THROTTLE AND INTEGRATED LATERAL AXIS FOR AUTOPILOT/YAW DAMPER FOR NASA TSRV AIRPLANE USING INTEGRAL LQG METHODOLOGY Final Report**

ISAAC KAMINER, RUSSELL A. BENSON, EDWARD E. COLEMAN, and YAGHOOB S. EBRAHIMI Washington Jan. 1990 152 p (Contract NAS1-18027) (NASA-CR-4268; NAS 1.26:4268) Avail: NTIS HC A08/MF A01 CSCL 01/3

Two designs are presented for control systems for the NASA Transport System Research Vehicle (TSRV) using integral Linear Quadratic Gaussian (LQG) methodology. The first is an integrated longitudinal autopilot/autothrottle design and the second design is an integrated lateral autopilot/yaw damper/sideslip controller design. It is shown that a systematic top-down approach to a complex design problem combined with proper application of modern control synthesis techniques yields a satisfactory solution in a reasonable period of time. Author

## **N90-16770# Georgia Inst. of Tech., Atlanta. School of Electrical Engineering.**

### **ESTIMATION AND CONTROL OF NONLINEAR AND HYBRID SYSTEMS WITH APPLICATIONS TO AIR-TO-AIR GUIDANCE Final Report, 1 Aug. 1987 - 31 Mar. 1989**

A. H. HADDAD and E. I. VERRIEST 31 Mar. 1989 169 p (Contract AF-AFOSR-0308-87; AF PROJ. 2304) (AD-A214542; AFOSR-89-1339TR) Avail: NTIS HC A08/MF A01 CSCL 17/7

The research covered several aspects of the basic issues that are needed to develop and implement nonlinear and hybrid systems schemes for the filtering, tracking, and control of maneuvering vehicles in an uncertain and nonlinear geometry. It is based on the approximation of the original nonlinear problem by a switched Markov linear models which in turn lead to hybrid model formulation or to piecewise linear approximations. Four aspects are considered: (1) Approaches to handling hybrid systems models; (2) Fast and slow decomposition for piecewise linear systems; (3) Estimation in the presence of impulsive inputs that can serve as either models for the switching behavior or the changes in maneuvers; and (4) Modeling, parameterization, and

realization issues for hybrid systems. Applications to nonlinear filtering and tracking schemes and their implementation is also addressed. GRA

**N90-17639\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF THE QUIET SHORT-HAUL RESEARCH AIRCRAFT (QSRA)**

JACK D. STEPHENSON and GORDON H. HARDY Washington Dec. 1989 43 p  
(NASA-TP-2965; A-89133; NAS 1.60:2965) Avail: NTIS HC A03/MF A01 CSCL 01/3

Flight experiments were conducted to evaluate various aerodynamic characteristics of the Quiet Short-Haul Research Aircraft (QSRA), an experimental aircraft that makes use of the upper-surface blown (USB) powered-lift concept. Time-history records from maneuvers performed with the aircraft in landing-approach and take-off configurations (with its stability augmentation system disengaged) were analyzed to obtain longitudinal stability and control derivatives and performance characteristics. The experiments included measuring the aircraft responses to variations in the deflection of direct-lift control spoilers and to thrust variations as well as to elevator inputs. The majority of the results are given for the aircraft in a landing configuration with the USB flaps at 50 degrees. For this configuration, if the static longitudinal stability is defined as the variation of the pitching-moment coefficient with the lift coefficient at a constant thrust coefficient, this stability decreases significantly with increasing angle of attack above 9 degrees. For this configuration, at small and negative angles of attack and high levels of thrust, the elevators and the horizontal stabilizer lost effectiveness owing to incipient stalling, but this occurred only during unsteady maneuvers and for brief time intervals. Author

**N90-17640#** National Aerospace Lab., Tokyo (Japan). **DEVELOPMENT OF THE TRIPLEX DIGITAL FLIGHT CONTROL SYSTEM OF THE STOL RESEARCH AIRCRAFT ASKA**

Feb. 1989 96 p In JAPANESE; ENGLISH summary  
(NAL-TR-1013; ISSN-0389-4010) Avail: NTIS HC A05/MF A01

National Aerospace Laboratory has been developing the STOL research aircraft named ASKA which underwent its maiden flight on October 28th, 1985. This project was started for the purpose of establishing STOL technology in Japan. In order to improve the stability and control of the ASKA in the low air speed region, the ASKA has a triplex digital stability and control augmentation system (SCAS) in which new technologies are introduced. Given here are an outline of design objectives, functions, a series of development tests, and results of the SCAS which include triplex digital computer systems, a triplex force summing electro hydraulic series servo actuator, a head-up display, and a low airspeed sensor. Most of the development tests were devoted to verifying the system hardware and software through control system functional mockup tests, and flight simulator tests connecting with the digital computer systems. The overall functions of the SCAS were tested in actual flight and the problems encountered during these tests are also presented. Author

**N90-17641\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**EQUATIONS OF MOTION OF SLUNG LOAD SYSTEMS WITH RESULTS FOR DUAL LIFT**

LUIGI S. CICOLANI and GERD KANNING Feb. 1990 40 p  
(NASA-TM-102246; A-89270; NAS 1.15:102246) Avail: NTIS HC A03/MF A01 CSCL 01/3

General simulation equations are derived for the rigid body motion of slung load systems. These systems are viewed as consisting of several rigid bodies connected by straight-line cables or links. The suspension can be assumed to be elastic or inelastic, both cases being of interest in simulation and control studies. Equations for the general system are obtained via D'Alembert's principle and the introduction of generalized velocity coordinates. Three forms are obtained. Two of these generalize previous

case-specific results for single helicopter systems with elastic or inelastic suspensions. The third is a new formulation for inelastic suspensions. It is derived from the elastic suspension equations by choosing the generalized coordinates so as to separate motion due to cable stretching from motion with invariant cable lengths. The result is computationally more efficient than the conventional formulation, and is readily integrated with the elastic suspension formulation and readily applied to the complex dual lift and multilift systems. Equations are derived for dual lift systems. Three proposed suspension arrangements can be integrated in a single equation set. The equations are given in terms of the natural vectors and matrices of three-dimensional rigid body mechanics and are tractable for both analysis and programming. Author

**N90-17642** Cincinnati Univ., OH. **DIRECT MULTIVARIABLE ADAPTIVE CONTROLLER WITH APPLICATION TO WING FLUTTER** Ph.D. Thesis

RAFAEL LIVNEH 1989 269 p  
Avail: Univ. Microfilms Order No. DA9003255

The problem of designing a robust simplified adaptive controller for the control of a wing flutter vibration is studied. The Direct Multivariable Model Reference Adaptive Control (DMMRAC) algorithm developed in Bar-Kana et al. is extended to include independent excitations to both the input and output of the plant. Those excitations are partitioned into measurable and unmeasurable parts and are incorporated into the ideal trajectory and into the adaptive law. The stability of the adaptive law is proved by using ultimate boundedness results for non-autonomous systems. The property of Almost Strict Positive Realness is thoroughly examined and related to the concepts of collocated sensors and actuators, stable transmission zeros, output stabilizability and the solution of the steady state Riccati equation. The numerical simulations of the wing control problem demonstrates stability and robustness over a wide range of variations in the simulation parameters. Dissert. Abstr.

**N90-17643#** Army Aviation Research and Development Command, Fort Eustis, VA. Aviation Applied Technology Directorate.

**FORCE DETERMINATION SENSITIVITIES STUDY FOR FULL-SCALE HELICOPTER GROUND VIBRATION TESTING** Memorandum Report

NICK CALAPODAS and KEITH HOFF Sep. 1989 63 p  
(AD-A215983; AD-F800086; USAAVSCOM-TM-89-D-4) Avail: NTIS HC A04/MF A01 CSCL 01/3

A fundamental objective of the Army's research and development efforts is to increase the reliability of the Army's air mobility force, which consists primarily of rotary-wing aircraft. Excessive vibrations have always been a problem for helicopters due to the vibratory airloads generated by the main rotor as it moves edgewise through the air. Maintenance and part replacement costs require that potential vibration problems be diagnosed as early as possible in the helicopter development and fielding cycle. A methodology known as Force Determination which was developed in the early 1970's is applicable to early diagnosis of vibration-induced problems. The objective of this program was to evaluate the limitations and accuracy of the Force Determination method. Controlled laboratory experiments and numerous sensitivity studies were performed to assess the validity of this method. GRA

**N90-17644#** Army Aviation Research and Development Command, Fort Eustis, VA. Aviation Applied Technology Directorate.

**THE ADVANCED DIGITAL-OPTICAL CONTROL SYSTEM (ADOCS) USER DEMONSTRATION PROGRAM** Final Report, Apr. - Sep. 1987

JOEL L. TERRY, JR., JOSEPH D. DICKINSON, and GARY D. JERAULD Sep. 1989 44 p  
(Contract DAAK51-82-C-0002; DA PROJ. 1L1-63211-D-436)  
(AD-A215984; AD-F800085; USAAVSCOM-TM-89-D-2) Avail: NTIS HC A03/MF A01 CSCL 17/7

This report documents the guest/user pilot assessment of the

## 08 AIRCRAFT STABILITY AND CONTROL

Advanced Digital-Optical Control System (ADOCS) installed in the JUH-60A Light Hawk helicopter. The assessment was performed by 76 guest/user pilots from government, industry, and the news media. Pilot comments were collected on the performance of the ADOCS fly-by-light control system relative to the Primary Flight Control System (PFCS), The Automatic Flight Control System (AFCS) (Core and Selectable modes), and the force-type sidearm controllers. Several areas for improvements were identified.

GRA

**N90-17646#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

### **STABILITY CHARACTERISTICS OF A COMBAT AIRCRAFT WITH CONTROL SURFACE FAILURE M.S. Thesis**

STEPHEN M. ZAISER Nov. 1989 147 p  
(AD-A216196; AFIT/GAE/ENY/89D-42) Avail: NTIS HC  
A07/MF A01 CSCL 01/1

In this thesis, an investigation of the stability characteristics of an aircraft which has sustained damage to a primary control surface was performed. The analysis was performed using wind tunnel data taken on an F-16 model in a test. The coupled, non-linear, aircraft equilibrium equations for constant altitude, rectilinear flight were derived. The aircraft stability and control derivatives were developed and analyzed to identify aerodynamic coupling with implications for an aircraft with failed control surface(s). Three control schemes which allow for progressively greater independence among the control surfaces were formulated for use in the evaluation of an aircraft with an actuator failure of the rudder. The investigations were conducted at two flight conditions representative of the aircraft at cruise and landing approach velocities. Regions in alpha/beta space where equilibrium is obtainable were investigated to identify remaining control authority, drag characteristics, and aircraft orientation. The matrix decomposition techniques of Singular Value Decomposition and the Row Reduced Echelon Form of the augmented matrix were used to provide additional insight into the interrelationship of the control surfaces at different points within the defined trim region.

GRA

## 09

### **RESEARCH AND SUPPORT FACILITIES (AIR)**

Includes airports, hangars and runways; aircraft repair and overhaul facilities; wind tunnels; shock tube facilities; and engine test blocks.

**A90-24151**

### **PERMEABILITY OF THE POROUS WALLS OF A WIND TUNNEL AT TRANSONIC VELOCITIES [PRONITSAEMOST' PERFORIROVANNYKH STENOK AERODINAMICHESKOI TRUBY PRI OKOLOZVUKOVYKH SKOROSTIAKH]**

V. M. NEILAND TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 142-146. In Russian. refs  
Copyright

A new method is proposed for determining the permeability parameter (proportionality factor in Darcy's law) of the porous walls of a wind tunnel for nearly sonic flow velocities. Examples are presented to illustrate the determination of this parameter for three different wind tunnels with walls of varying porosity, and the results are compared with data in the literature.

V.L.

**A90-24169**

### **INTERFERENCE BETWEEN THE PITOT-STATIC TUBE AND THE MODEL IN WIND TUNNEL STUDIES OF FLOW PARAMETERS [VZAIMNOE VLIANIE PRIEMNIKA VOZDUSHNOGO DAVLENIIA I MODELI V ISSLEDOVANIYAKH PARAMETROV POTOKA V AERODINAMICHESKOI TRUBE]**

D. A. BESSONOV and G. V. GURA TsAGI, Uchenye Zapiski

(ISSN 0321-3429), vol. 19, no. 6, 1988, p. 119-124. In Russian. Copyright

The problem considered here concerns numerical modeling of an aerodynamic experiment in which a conical pitot-static tube is used to measure local Mach numbers and downwash angles in flow past a wing/fuselage configuration. The approach used here takes account of the flow perturbation introduced by the pitot-static tube in the vicinity of the aircraft model, which improves the reliability of experimental results. Calculations based on the panel method are compared with experimental data.

V.L.

**A90-24359#**

### **A MICROPROCESSOR-BASED SYSTEM FOR MONITORING GAS TURBINES**

P. K. S. SHRIVASTAVA, R. P. ARORA, and JASBIR SINGH (Institute of Armament Technology, Poona, India) Defence Science Journal (ISSN 0011-748X), vol. 39, April 1989, p. 121-131. refs

The design and operation of a computer-based automatic gas-turbine monitoring system for shipboard use are described. The system is implemented on an 8085 microprocessor and keeps track of running hours, the slip between high-pressure and low-pressure compressor spools, and the torque on the reduction gearbox. The software occupies about 12 kbytes and is stored on an EPROM chip. Flow charts of the monitoring algorithm and graphs and sample printouts of the system output are provided.

T.K.

**A90-25027#**

### **AERODYNAMIC HEAT TRANSFER TESTING IN HYPERSONIC WIND TUNNELS USING AN INFRARED IMAGING SYSTEM**

ARNOLD S. COLLIER, JOHN F. LAFFERTY, SCOTT S. SWINFORD (U.S. Navy, Naval Surface Warfare Center, Silver Spring, MD), and D. W. WITTE (North Carolina State University, Raleigh) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 12 p.  
(AIAA PAPER 90-0189)

A wind tunnel test was conducted to determine whether it was possible to measure the surface temperature of a typical stainless-steel model using a commercially available infrared imaging system. The tests were conducted in the NSWC Hypervelocity Wind Tunnel No. 9 at Mach 14. The model used was an 8-deg-half-angle cone with a cylindrical protuberance attached to it. The temperature data from the camera were compared to coaxial thermocouple measurements of the same surface. A one- and two-dimensional numerical heat-transfer analysis was performed on the coax data. The results obtained show that temperature measurements of the surface of an untreated stainless-steel model cannot be made accurately. The emittance of the model surface must be enhanced.

Author

### **A90-25040\*# Boeing Helicopter Co., Philadelphia, PA. SPRAY NOZZLE INVESTIGATION FOR THE IMPROVED HELICOPTER ICING SPRAY SYSTEM (IHSS)**

ANDREW A. PETERSON (Boeing Helicopters, Philadelphia, PA) and JOHN R. OLDENBURG (NASA, Lewis Research Center, Cleveland, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. refs  
(AIAA PAPER 90-0666) Copyright

A contract has been awarded by the U.S. Army to design, fabricate and test a replacement for the existing Helicopter Icing Spray System. Data are shown for extensive bench and icing tunnel test programs used to select and modify an improved spray nozzle. The IHSS, capable of deployment from any CH-47 helicopter, will include new icing spray nozzles and pneumatic pressure source, and a significantly larger water tank and spray boom. The resulting system will provide a significantly larger icing cloud with droplet characteristics closely matching natural icing conditions.

R.E.P.

**A90-25165\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

### **EXPERIENCE WITH SCALE EFFECTS IN NON-AIRPLANE WIND TUNNEL TESTING**

J. C. ROSS (NASA, Ames Research Center, Moffett Field, CA) and M. E. OLSON (Navistar International Transportation Corp., Fort Wayne, IN) AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 10 p. refs (AIAA PAPER 90-1822)

The aerodynamics results of two tests performed in the 80- by 120-Foot Wind Tunnel at NASA Ames Research Center are discussed with particular emphasis on the effects of model scale. The tests are unusual for this facility in that they were performed on non-airplane configurations: a full-scale tractor/trailer and large ramair inflated wings. For the truck drag measurements, comparisons with 1/8th-scale drag data taken at the Low Speed Wind Tunnel at Texas A&M indicate that small scale measurements can provide adequate accuracy if care is taken to test at high enough Reynolds numbers and if large regions of separated flow and reattachment are avoided. Some of the important aerodynamic and structural aspects of parafoil testing are also discussed. These include the effects of Reynolds number and aeroelastic effects such as fabric and support line stretch. Author

### A90-25351#

#### **DETERMINATION OF CONVECTIVE TRANSFER COEFFICIENTS ON A WIND-TUNNEL MODEL BY STIMULATED INFRARED THERMOGRAPHY (DETERMINATION DES COEFFICIENTS DE TRANSFERT CONVECTIF SUR UNE MAQUETTE EN SOUFFLERIE PAR THERMOGRAPHIE INFRAROUGE STIMULEE)**

D. BALAGEAS, D. BOSCHER, P. DELPECH, and A. DEOM (ONERA, Chatillon-sous-Bagneux, France) (Societe Francaise des Thermiciens, Journee d'Etude, Paris, France, Nov. 29, 1989) ONERA, TP no. 1989-218, 1989, 16 p. In French. Research supported by DRET and Matra, S.A. refs (ONERA, TP NO. 1989-218)

Infrared thermography is now being used in windtunnels and in flight to detect and localize transition zones. Progress in thermal infrared imaging instruments allows precise determination of stationary fields of surface temperatures. Various thermographic measurement methods are presented, including passive thermography in which heating of the mockup is due only to convection; and stimulated thermography using a short-duration radiative flux. Examples of practical wind-tunnel measurements are presented. R.E.P.

### A90-25358#

#### **EUROPEAN RESEARCH AND TESTING FACILITIES REQUESTED FOR PARTICIPATION TO SST/HST PROJECTS**

G. KOPPENWALLNER (DLR; Hyperschall-Technologie Goettingen, Federal Republic of Germany) and G. DOREY (ONERA, Chatillon-sous-Bagneux, France) (European Symposium on Future Supersonic/Hypersonic Transportation, Strasbourg, France, Nov. 6-8, 1989) ONERA, TP no. 1990-12, 1990, 12 p. refs (ONERA, TP NO. 1990-12)

Results are presented from an analysis to determine the requirements for facilities to study and develop HST aircraft. Consideration is given to the vehicle concepts and flight conditions and aerodynamic problems areas that would be studied at SST/HST facilities. The general approach for simulation and development tests of an HST aircraft is outlined. Characteristic requirements are given for aerodynamic hypersonic testing, propulsion and propulsion integration testing, and thermal structural testing. R.B.

### A90-26061

#### **LOW SPEED, INDRAFT WIND TUNNELS**

STEPHEN M. BATILL and ROBERT C. NELSON (Notre Dame, University, IN) IN: Frontiers in experimental fluid mechanics. Berlin and New York, Springer-Verlag, 1989, p. 25-94. Research supported by the University of Notre Dame and USAF. refs Copyright

The general design and operation of low-speed indraft wind tunnels are reviewed. The design variables for each of the major wind tunnel components are identified, and their influence on the tunnel performance is assessed. In particular, the discussion covers

general design considerations, turbulence management devices, inlet section, test section, diffuser, and power system. The importance of system integration is emphasized. V.L.

A90-26133\*# National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

#### **COMPARISON OF MODEL- AND FULL-SCALE WIND-TUNNEL PERFORMANCE**

BRIAN E. SMITH, PETER T. ZELL (NASA, Ames Research Center, Moffett Field, CA), and PATRICK M. SHINODA (U.S. Army, Aviation Systems Command, Moffett Field, CA) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 232-238. refs (AIAA PAPER 88-2536)

Experimental results from the Integrated Systems Test of the upgraded National Full-Scale Aerodynamics Complex 40- by 80-ft wind tunnel located at NASA Ames Research Center, which took place in 1987, are compared with results obtained with a 1/50 scale model of the wind tunnel. Test-section flow characteristics, air-exchange performance, total pressure distributions, and wall-static pressure distributions obtained with the model- and full-scale facilities are compared. The 1/50-scale model data were used to predict qualitative performance trends of the full-scale facility during investigation of design changes. Despite large differences in scale and Reynolds number between the two tunnels, quantitative agreement between certain model and full-scale performance characteristics was quite good. Author

### A90-26203#

#### **REALTIME GRAPHIC FLIGHT SIMULATIONS USING MULTIPLE MINICOMPUTERS**

JEFFERY L. MARESH and ROBERT E. TODD (Enterprise Technology, Columbus, OH) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 221-226.

This paper addresses the various technical aspects of the hardware and software used to perform realtime graphic flight simulations using two minicomputers. A MicroVAX II has been utilized to perform the computation of aircraft state, subject control input, and data collection while an IRIS 3020 has been used to display high resolution graphic images of the vehicle flight path. These tasks have been apportioned between two minicomputers to take advantage of each computer's respective architecture. Using this configuration, high fidelity simulations have been attained at a 33 Hertz frame rate. The attributes of a good development environment in this configuration are also discussed. Author

### A90-26351#

#### **ADAPTIVE WALL WIND TUNNELS - MARRIAGE BETWEEN EXPERIMENTS AND COMPUTATIONS**

M. A. RAMASWAMY (Indian Institute of Science, Bangalore, India) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 41, Nov. 1989, p. 449-461. refs

Research using adaptive wall wind tunnels is reviewed. Problems associated with experiments and computations involving transonic speeds are addressed. The principle of adaptive wall wind tunnels and the iterative and one-step wall adaptive schemes are examined. The adaptive wall test sections in use are listed and several research facilities are described. Also, an overview of results obtained using adaptive wall wind tunnels is given. R.B.

### A90-26753

#### **DEVELOPMENT OF JET TRANSPORT AIRFRAME FATIGUE TEST SPECTRA**

KEVIN R. FOWLER and ROY T. WATANABE (Boeing Commercial Airplanes, Seattle, WA) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 36-64. refs

Copyright

Full-scale airframe fatigue tests are conducted in order to demonstrate economical maintainability in service; these tests are accelerated relative to actual use, so that areas exhibiting early fatigue problems can be identified and corrected in timely fashion.



## 09 RESEARCH AND SUPPORT FACILITIES (AIR)

Attention is presently given to airframe fatigue test spectra for the 757 and 767 airliners which were based on the application of loads as realistically as possible, while conforming to program schedule and test equipment limitations. Load magnitudes and frequencies, applied in blocks of 5000 flights (using five different flight types) met observed statistical criteria without relying on damage-model assumptions. Test-time objectives were met by tailoring the spectra-truncation levels. O.C.

### A90-26842

#### AIR/WATER TWO-PHASE FLOW TEST TUNNEL FOR AIRFOIL STUDIES

H. OHASHI, Y. MATSUMOTO, Y. ICHIKAWA, and T. TSUKIYAMA (Tokyo, University, Japan) Experiments in Fluids (ISSN 0732-4864), vol. 8, no. 5, 1990, p. 249-256. refs  
Copyright

A test tunnel for the study of airfoil performances under air/water two-phase flow condition has been designed and constructed. At the test section of the tunnel, a two-dimensional isolated airfoil or a cascade of airfoils is installed in a two-phase inlet flow with a uniform velocity (up to 10 m/s) and void fraction (up to 12 percent) distribution. The details of the tunnel structure and the measuring systems are described, and the basic characteristics of the constructed tunnel are also given. As an example of the test results, void fraction distribution around a test airfoil is shown.

Author

### A90-26974#

#### THE INTEGRATED TEST VEHICLE, (I.T.V.) - A VEHICLE FOR COST-EFFECTIVE HYPERSONIC TESTING

JAMES R. HEYES and RICHARD D. NEUMANN (USAF, Flight Dynamics Laboratory, Wright-Patterson AFB, OH) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 11 p. refs  
(AIAA PAPER 90-0630)

The concept of the integrated test vehicle (ITV) is proposed. The ITV concept needs to combine the collection and analysis of heat transfer, pressure, and force and moment balance data. The phase development and validation of the hardware are described. Test data from phase I reveal that the ITV concept is technically possible, but upgrades are required. The advantages of the ITV concept compared to traditional wind tunnel testing techniques are discussed. Consideration is given to dynamic instrumentation, smart sensors, micromachining techniques, the use of work stations to display data, and applying AI to the acquisition of wind tunnel data. I.F.

### A90-26979#

#### A COMPARISON OF A DROPLET IMPINGEMENT CODE TO ICING TUNNEL RESULTS

G. TENISON (BF Goodrich De-Icing Systems, Uniontown, OH), M. BRAGG, and K. FARAG (Ohio State University, Columbus) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. refs  
(AIAA PAPER 90-0670) Copyright

A three-dimensional droplet impingement code based on a potential flow field solver has been developed to aid in the design of deicing systems for aircraft. The computational method and numerical procedure involved in the code are discussed, and the experimental validation of the code is described, including the test facility, test calibration, and test procedure. Significant experimental errors which occurred during the validation are identified. C.D.

### N90-16773# Southwest Research Inst., San Antonio, TX. CUMULATIVE AIRPORT NOISE EXPOSURE METRICS: AN ASSESSMENT OF EVIDENCE FOR TIME-OF-DAY WEIGHTINGS, REVISION

JAMES M. FIELDS Nov. 1989 180 p  
(AD-A214878; DOT/FAA/EE-86/10-REV) Avail: NTIS HC A09/MF A02 CSCL 20/1

The differential impact of noise on residents at different times of day is examined in analyses of the original machine-readable

data from ten community surveys and in detailed reviews of the published results from 20 additional surveys. Analyses are conducted using alternative community response measures and analysis techniques. The primary objective of these analyses is to determine the relative impact of noise during the daytime and nighttime by estimating the value of a time-day weighting in the adjusted energy model. Some support is found for nighttime and evening weightings, however, the estimates of these time-of-day weightings are found to be highly accurate. Examinations of the factors affecting this accuracy lead to the conclusion that studies of community response to noise will not provide a usefully accurate estimation of the time-of-day weighting parameter in the adjusted energy model. Data is provided on proportions of the United States population engaged in noise-sensitive activities at different times of day. All social survey results are reproduced in which averages of nighttime response are plotted by nighttime noise levels. Analyses are conducted of the relationship between daytime and nighttime noise environments around United States airports.

GRA

### N90-17647\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

#### CAST-10-2/DOA 2 AIRFOIL STUDIES WORKSHOP RESULTS

EDWARD J. RAY, comp. and ACQUILLA S. HILL, comp. Washington Nov. 1989 259 p Workshop held in Hampton, VA, 23-27 Sep. 1988  
(NASA-CP-3052; L-16633; NAS 1.55:3052) Avail: NTIS HC A12/MF A02 CSCL 14/2

During the period of September 23 through 27, 1988, the Transonic Aerodynamics Division at the Langley Research Center hosted an International Workshop on CAST-10-2/DOA 2 Airfoil Studies. The CAST-10 studies were the outgrowth of several cooperative study agreements among the NASA, the NAE of Canada, the DLR of West Germany, and the ONERA of France. Both theoretical and experimental CAST-10 airfoil results that were obtained form an extensive series of tests and studies, were reviewed. These results provided an opportunity to make direct comparisons of adaptive wall test section (AWTS) results from the NASA 0.3-meter Transonic Cryogenic Tunnel and ONERA T-2 AWTS facilities with conventional ventilated wall wind tunnel results from the Canadian high Reynolds number two-dimensional test facility. Individual papers presented during the workshop are included.

### N90-17648\*# National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

#### NONLINEAR TRANSONIC WALL-INTERFERENCE ASSESSMENT/CORRECTION (WIAC) PROCEDURES AND APPLICATION TO CAST-10 AIRFOIL RESULTS FROM THE NASA 0.3-M TCT 8- BY 24-INCH SLOTTED WALL TEST SECTION (SWTS)

CLYDE R. GUMBERT, LAWRENCE L. GREEN, and PERRY A. NEWMAN In its CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 9-35 Nov. 1989  
Avail: NTIS HC A12/MF A02 CSCL 14/2

From the time that wind tunnel wall interference was recognized to be significant, researchers have been developing methods to alleviate or account for it. Despite the best effort so far, it appears that no method is available which completely eliminates the effects due to the wind tunnel walls. This report discusses procedures developed for slotted wall and adaptive wall test sections of the Langley 0.3-m Transonic Cryogenic Tunnel (TCT) to assess and correct for the residual interference by methods consistent with the transonic nature of the tests. Author

### N90-17649\*# Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Goettingen (Germany, F.R.). Inst. fuer Experimentelle Stroemungsmechanik.

#### COMPARISON OF CONVENTIONAL AND ADAPTIVE WALL WIND TUNNEL RESULTS WITH REGARD TO REYNOLDS NUMBER EFFECTS

E. STANEWSKY and P. FREIMUTH In NASA, Langley Research



Center, CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 37-46 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 14/2

A comparison of results from conventional and adaptive wall wind tunnels with regard to Reynolds number effects was carried out. The special objective of this comparison was to confirm or reject earlier conclusions, solely based on conventional wind tunnel results, concerning the influence of viscous effects on the characteristics of partially open wind tunnel walls, hence wall interference. The following postulations could be confirmed: (1) certain classes of supercritical airfoils exhibit a non-linear increase in lift which is, at least in part, related to viscous-inviscid interactions on the airfoil. This non-linear lift characteristic can erroneously be suppressed by sidewall interference effects in addition to being affected by changes in Reynolds number. Adaptive walls seem to relieve the influence of sidewall interference; (2) the degree of (horizontal) wall interference effects can be significantly affected by changes in Reynolds number, thus appearing as true Reynolds number effects; (3) perforated wall characteristics seem much more susceptible to viscous changes than the characteristics of slotted walls; here, blockage interference may be most severely influenced by viscous changes; and (4) real Reynolds number effects are present on the CAST 10-2/DOA 2 airfoil; they were shown to be appreciable also by the adaptive wall wind tunnel tests. K.C.D.

**N90-17655\*#** National Aeronautical Establishment, Ottawa (Ontario).

#### **RESIDUAL INTERFERENCE AND WIND TUNNEL WALL ADAPTION**

MIROSLAV MOKRY *In* NASA, Langley Research Center, CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 175-193 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 14/2

Measured flow variables near the test section boundaries, used to guide adjustments of the walls in adaptive wind tunnels, can also be used to quantify the residual interference. Because of a finite number of wall control devices (jacks, plenum compartments), the finite test section length, and the approximation character of adaptation algorithms, the unconfined flow conditions are not expected to be precisely attained even in the fully adapted stage. The procedures for the evaluation of residual wall interference are essentially the same as those used for assessing the correction in conventional, non-adaptive wind tunnels. Depending upon the number of flow variables utilized, one can speak of one- or two-variable methods; in two dimensions also of Schwarz- or Cauchy-type methods. The one-variable methods use the measured static pressure and normal velocity at the test section boundary, but do not require any model representation. This is clearly of an advantage for adaptive wall test section, which are often relatively small with respect to the test model, and for the variety of complex flows commonly encountered in wind tunnel testing. For test sections with flexible walls the normal component of velocity is given by the shape of the wall, adjusted for the displacement effect of its boundary layer. For ventilated test section walls it has to be measured by the Calspan pipes, laser Doppler velocimetry, or other appropriate techniques. The interface discontinuity method, also described, is a genuine residual interference assessment technique. It is specific to adaptive wall wind tunnels, where the computation results for the fictitious flow in the exterior of the test section are provided. Author

**N90-17656\*#** National Aeronautics and Space Administration, Langley Research Center, Hampton, VA.

#### **COMPARISON OF NAE POROUS WALL AND NASA ADAPTIVE WALL TEST RESULTS USING THE NAE CAST-10 AIRFOIL MODEL**

RAYMOND E. MINECK *In its* CAST-10-2/DOA 2 Airfoil Studies Workshop Results p 195-212 Nov. 1989

Avail: NTIS HC A12/MF A02 CSCL 14/2

Wind tunnels can now simulate flows over airfoils at high Reynolds numbers and high subsonic speeds. Methods to correct for (or reduce) test section wall interference at these test conditions must be validated. The National Aeronautics Establishment (NAE)

of Canada and NASA have a cooperative agreement to study this area. The NAE designed, built, and tested a CAST-10 airfoil model in its conventional Two-Dimensional High Reynolds Number Facility. The results were corrected using classical correction techniques. NASA then tested the same model in its 0.3-meter Transonic Cryogenic Tunnel with the adaptive wall test section. The adaptive wall test section reduced the wall interference to what was expected to be an acceptable level. The corrected NAE results are compared with the uncorrected NASA results. The NAE results are also compared with NASA results after residual corrections for top and bottom wall interference. Finally, a comparison of both sets of results corrected for interference from all four walls is presented.

Author

## 10

### ASTRONAUTICS

Includes astronautics (general); astrodynamics; ground support systems and facilities (space); launch vehicles and space vehicles; space transportation; spacecraft communications, command and tracking; spacecraft design, testing and performance; spacecraft instrumentation; and spacecraft propulsion and power.

**A90-25172#**

#### **RECOVERY CONCEPTS FOR PROPULSION AND AVIONICS COMPONENTS**

D. S. PARKMAN (Boeing Aerospace and Electronics, Seattle, WA) AIAA, Aerospace Engineering Conference and Show, Los Angeles, CA, Feb. 13-15, 1990. 10 p.

(AIAA PAPER 90-1810) Copyright

A study is made on the recovery of high value hardware to lower launch costs and make operability more affordable. It is shown that redundancy is made affordable by recovery and reuse, allowing amortization of the hardware costs over multiple flights. Concepts for both booster stage and core stage hardware recovery have been studied. Booster hardware lands in the ocean but can be either immersed and salvaged or protected from the marine environment and retrieved. Core hardware can be either landed in the ocean or on land at the launch site. For land landing both ballistic body and lifting body vehicles have been studied. Studies and tests show that both water and land landing are technically achievable, can be done safely, reliably, and are operationally cost effective. These attributes are achieved by protecting hardware landing in the ocean from the marine environment to prevent high engine refurbishment costs and by using a ballistic body vehicle which is the simplest, lightest, and safest vehicle design approach and can be configured for water and/or land landing. R.E.P.

**A90-25781#**

#### **THE DESIGN OF SUPERSONIC AIRCRAFT AND SPACE VEHICLES BY USING GLOBAL OPTIMIZATION TECHNIQUES**

ADRIANA NASTASE (Aachen, Rheinisch-Westfaelische Technische Hochschule, Federal Republic of Germany) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 459-464. refs

The successful application of the author's optimum-optimum theory to the full optimization of the shape of a variable geometry space vehicle at two cruising Mach numbers is demonstrated. The resulting integrated wing-fuselage configuration with minimum drag can be applied to supersonic transport aircraft of the future and to two-stage space vehicles. Another result is the integrated wing-fuselage-flaps configuration with variable geometry applicable to one-stage space vehicles. C.D.

**N90-16800#** British Aerospace Public Ltd. Co., Stevenage (England). Space Systems Group.

#### **HOTOL: A FUTURE LAUNCHER FOR EUROPE**

PETER J. CONCHIE *In* ESA, Progress in Space Transportation  
p 143-148 Aug. 1989  
Copyright Avail: NTIS HC A22/MF A03

The need for a European aerospace plane is presented. The role of HOTOL in raising the profile of such an aerospace plane is described. The current status of the HOTOL program is outlined. Diagrams of the HOTOL aerospace plane are presented. Vehicle configuration interactions, command and control issues, and aerodynamic design criteria are illustrated. Concerning budget, operational support systems are calculated to be the biggest single item in determining HOTOL costs. ESA

**N90-16814#** British Aerospace Public Ltd. Co., Preston (England). Military Aircraft Div.

**AERODYNAMIC AND STRUCTURAL DESIGN CHALLENGES OF A REUSABLE SINGLE STAGE TO ORBIT AIR-BREATHING LAUNCH VEHICLE**

BRIAN R. A. BURNS *In* ESA, Progress in Space Transportation  
p 255-260 Aug. 1989  
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The need for a new advanced space transport early in the next century is outlined. The advantages of single stage to orbit systems are discussed. Design sensitivity problems are noted. Problems of pitch control and their solution are described. The design of each major component of HOTOL is outlined, covering aerodynamic, structure, materials and systems aspects. A successful simulation of autoland in a variety of wind conditions is summarized. ESA

**N90-16827#** Deutsche Forschungsanstalt fuer Luft- und Raumfahrt, Brunswick (Germany, F.R.).

**HERMES TRAINING AIRCRAFT**

DIETRICH HANKE and GENENE GARGIR (Centre National d'Etudes Spatiales, Toulouse, France) *In* ESA, Progress in Space Transportation p 357-364 Aug. 1989  
Copyright Avail: NTIS HC A22/MF A03

The Hermes Training Aircraft (HTA) flight simulator is described. It is designed to train Hermes pilots and crew for the steep, unpowered landing approach trajectory. The HTA is able to simulate approach trajectories from an altitude of 37,000 ft. to touchdown under real environmental conditions. Based on the training mission requirements, the simulation concept design, simulation equipment and host aircraft modifications are presented. ESA

**N90-16842#** Messerschmitt-Boelkow-Blohm G.m.b.H., Munich (Germany, F.R.).

**VERIFICATION OF AEROTHERMODYNAMIC CODES BY MEANS OF A WINGED EXPERIMENTAL RE-ENTRY VEHICLE**

ERNEST HENRICH HIRSCHL and H. GRALLERT *In* ESA, Progress in Space Transportation p 485-500 Aug. 1989  
Sponsored in part by Avions Marcel Dassault-Breguet Aviation (Contract ESA-H-ST-13-01-AS)  
Copyright Avail: NTIS HC A22/MF A03

A verification database used in establishing methods of computational aerothermodynamics is described. These computational methods are intended to assist classical aerothermodynamic design tools such as wind tunnels. It is shown that wind tunnels cannot completely yield the data base needed. An experimental winged reentry vehicle is needed for this purpose. The potential database derived from such an experimental vehicle is discussed. Data from a reentry capsule is analyzed. A four-loop approach for the validation of the numerical codes is suggested. The database from the experimental vehicle is used as the final decisive database. The special needs of atmospheric hypersonic airplanes are discussed. ESA

## CHEMISTRY AND MATERIALS

Includes chemistry and materials (general); composite materials; inorganic and physical chemistry; metallic materials; nonmetallic materials; and propellants and fuels.

**A90-23751#**

**THE PROPERTIES AND CHARACTERISTICS OF ELECTROLESS NICKEL COATINGS APPLIED TO GAS TURBINE ENGINE COMPONENTS**

THOMAS W. BLEEKS and FRANK BRINDISI, JR. (Enthone, Inc., West Haven, CT) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p. refs (ASME PAPER 89-GT-4)

The improvement of reliability and reduction of overhaul time is of paramount importance to engineers involved with coatings used on gas turbine engine components. Aluminum/phosphate/chromate coatings are currently used in industrial and aircraft gas turbine engines for coating compressor components. Traditional electrolytic nickel with diffused cadmium coatings are also used but to a lesser extent. Field experience, however, has shown limitations with both coating systems, particularly in the areas of erosion, wear, and simplicity in component processability. Currently, several new electroless nickel coatings are gaining significant acceptance in the industry, both for overhaul and repair, as well as for new part manufacture. This paper presents erosion, corrosion, fatigue and stress data on these coatings. Some field experience is also presented from airline operators and overhaul facilities who are incorporating these coatings on aircraft gas turbine engine components. Information is also given on the capability of electroless nickel coatings to reduce manufacturing cost and simplify the processing of complex parts. Author

**A90-23839#**

**THERMAL BARRIER CHARACTERISTICS OF PARTIALLY STABILIZED ZIRCONIA COATINGS ON INCOLOY ALLOY 909 (A CONTROLLED EXPANSION ALLOY)**

GAYLORD D. SMITH (Inco Alloys International, Inc., Huntington, WV) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs (ASME PAPER 89-GT-146)

Incoloy alloy 909 is a low expansion alloy used in critical seal and shaft applications within the gas turbine engine. Since its coefficient of expansion is similar to that of partially stabilized zirconia for temperatures to 649 C, it is proposed that this metal-ceramic combination may be used for dimensionally critical, air cooled jet engine components. This coating system should extend temperature limitations by reducing metal temperatures and providing oxidation resistance. The performance advantage offered by a thermal barrier coating has been investigated at temperatures up to 1093 C and the results are presented in this paper. Author

**A90-23842\*#** Cleveland State Univ., OH.

**A REVIEW OF FAILURE MODELS FOR CERAMIC MATRIX COMPOSITE LAMINATES UNDER MONOTONIC LOADS**

DAVID E. TRIPP, JOHN H. HEMANN (Cleveland State University, OH), and JOHN P. GYKENYESI (NASA, Lewis Research Center, Cleveland, OH) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 13 p. Previously announced in STAR as N89-14470. refs (Contract NCC3-81) (ASME PAPER 89-GT-153)

Ceramic matrix composites offer significant potential for improving the performance of turbine engines. In order to achieve their potential, however, improvements in design methodology are needed. In the past most components using structural ceramic matrix composites were designed by trial and error since the

emphasis of feasibility demonstration minimized the development of mathematical models. To understand the key parameters controlling response and the mechanics of failure, the development of structural failure models is required. A review of short term failure models with potential for ceramic matrix composite laminates under monotonic loads is presented. Phenomenological, semi-empirical, shear-lag, fracture mechanics, damage mechanics, and statistical models for the fast fracture analysis of continuous fiber unidirectional ceramic matrix composites under monotonic loads are surveyed. Author

**A90-24116**

**EFFECT OF HYDROGEN COMBUSTION IN A SUPERSONIC BOUNDARY LAYER ON FRICTION COEFFICIENT [VLIANIE GORENIIA VODORODA V SVERKHZVUKOVOM POGRANICHNOM SLOE NA KOEFFITSIENT TRENNIA]**

O. M. KOLESNIKOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 104-109. In Russian. refs Copyright

Friction coefficients have been calculated for the case of the ignition and combustion of a plane nonisobaric hydrogen jet issuing along a plate into supersonic flow (free-stream Mach 2-20). For Mach less than 15, ignition is shown to reduce the friction coefficient by about 30-50 percent. This effect disappears at higher Mach numbers and in the case where ignition occurs at some distance away from the wall, rather than next to the wall. V.L.

**A90-24288**

**RECENT AND PROSPECTIVE DEVELOPMENTS IN SINGLE-CRYSTAL SUPERALLOYS FOR THE BLADES OF ADVANCED TURBINES [DEVELOPPEMENTS RECENTS ET POTENTIELS DES SUPERALLAGES MONOCRISTALLINS POUR LES AUBES DE TURBINES AVANCEES]**

T. KHAN (ONERA, Chatillon-sous-Bagneux, France) Revue Francaise de Mecanique (ISSN 0373-6601), no. 2, 1989, p. 171-187. In French. Research supported by DRET and Service Technique des Programmes Aeronautiques. refs Copyright

Techniques for the preparation of the low-density Ni-based superalloys required by advanced turbojet engines are described, with a focus on recent advances at ONERA. The high operating temperatures and strength requirements for aircraft engines are reviewed; the basic metallurgical research performed on specific elements and alloys is summarized; solidification methods are outlined; and techniques for gamma-prime solution and precipitation treatments are explained. Particular attention is then given to: (1) the creep properties of the superalloys (effects on deformation behavior, effects of processing conditions, anisotropic creep, and effects of thermal stability); (2) fatigue behavior; and (3) oxidation and corrosion properties. It is shown that optimum creep performance can be obtained with precipitates of size about 500 nm. Extensive graphs, micrographs, and tables of numerical data are included. T.K.

**A90-24861\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**INFLUENCE OF ALLOYING ELEMENTS ON THE OXIDATION BEHAVIOR OF NBAL3**

M. G. HEBSUR (NASA, Lewis Research Center; Sverdrup Technology, Inc., Cleveland, OH), J. R. STEPHENS, J. L. SMIALEK, C. A. BARRETT, and D. S. FOX (NASA, Lewis Research Center, Cleveland, OH) IN: Oxidation of high-temperature intermetallics; Proceedings of the Workshop, Cleveland, OH, Sept. 22, 23, 1988. Warrendale, PA, Minerals, Metals, and Materials Society, 1989, p. 171-183. Previously announced in STAR as N89-12717. refs Copyright

NbAl<sub>3</sub> is one candidate material for advanced aeropropulsion systems because of its high melting point, low density, and good oxidation resistance. Although NbAl<sub>3</sub> has the lowest oxidation rate among the binary Nb-Al alloys, it does not form exclusive layers of protective Al<sub>2</sub>O<sub>3</sub> scales. Recently Perkin et al., have shown the feasibility of forming alumina scales on Nb-Al alloys at greatly reduced Al contents. However, the objective was to maintain the

high Al content, and hence low density, while achieving the capability of growing protective alumina scales. Alloy development followed approaches similar to those used successfully for superalloys and oxidation resistant MCrAlY coatings. Among the three elements examined (Ti, Si, and Cr) as ternary additions to Nb-Al<sub>3</sub>, Cr was the most effective in favoring the selective oxidation of Al. Nb-41Al-8Cr formed exclusive layers of alumina and had a k sub p value of 0.22 mg squared/cm (sup 4)/hr at 1200 C. The addition of 1 wt percent Y to this alloy was also beneficial, resulting in nearly an order of magnitude decrease in K sub p at 1200 C. Further improvements were achieved by adding about 1 wt percent Si to the quaternary alloy. The k sub p value of 0.012 mg squared/cm (sup 4)/hr for Nb-40Al-8Cr-1Y-1Si at 1200 C was identical to the best NiAl + Zr alloys. These NbAl<sub>3</sub> alloys also exhibited excellent cyclic oxidation resistance for 100 hr at 1200 C, being nearly equivalent to NiAl + Zr. Author

**A90-24865**

**THE EFFECT OF ELEVATED TEMPERATURE EXPOSURE ON THE TENSILE AND CREEP PROPERTIES OF Ti-24AL-11NB**

STEPHEN J. BALSONE (USAF, Materials Laboratory, Wright-Patterson AFB, OH) IN: Oxidation of high-temperature intermetallics; Proceedings of the Workshop, Cleveland, OH, Sept. 22, 23, 1988. Warrendale, PA, Minerals, Metals, and Materials Society, 1989, p. 219-234. refs (Contract AF PROJECT 2302P101) Copyright

In order to ascertain the severity of environmental degradation in an intermetallic material's properties, tensile and sustained-load creep tests were conducted on Ti-24Al-11Nb, in both laboratory air and in vacuum, over the room temperature-750 C range. Metallographic and fractographic analyses were conducted on failed specimens. The results indicate that Ti-24Al-11Nb is subject to bulk alloy embrittlement in laboratory air at elevated temperature; the embrittled material cracks under loading, and the resulting notch prematurely initiates failure in a transgranular mode. O.C.

**A90-25267\*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**BURNER RIG HOT CORROSION OF SILICON CARBIDE AND SILICON NITRIDE**

DENNIS S. FOX and JAMES L. SMIALEK (NASA, Lewis Research Center, Cleveland, OH) American Ceramic Society, Journal (ISSN 0002-7820), vol. 73, Feb. 1990, p. 303-311. Research sponsored by DOE. refs Copyright

A number of commercially available SiC and Si<sub>3</sub>N<sub>4</sub> materials were exposed to 1000 C for 40 h in a high-velocity, pressurized burner rig as a simulation of an aircraft turbine environment. Na impurities (2 ppm) added to the burner flame resulted in molten Na<sub>2</sub>SO<sub>4</sub> deposition, attack of the SiC and Si<sub>3</sub>N<sub>4</sub>, and formation of substantial Na<sub>2</sub>O + x(SiO<sub>2</sub>) corrosion product. Room-temperature strength of the materials decreased as a result of the formation of corrosion pits in SiC and grain-boundary dissolution and pitting in Si<sub>3</sub>N<sub>4</sub>. Author

**A90-25339#**

**THE ANISOTROPY OF THE MECHANICAL BEHAVIOUR IN NICKEL-BASED SINGLE CRYSTAL SUPERALLOYS FOR TURBINE BLADES**

T. KHAN and P. CARON (ONERA, Chatillon-sous-Bagneux, France) (European Conference and Advanced Materials and Processes, Aachen, Federal Republic of Germany, Nov. 22-24, 1989) ONERA, TP no. 1989-205, 1989, 7 p. Research supported by DRET. refs (ONERA, TP NO. 1989-205)

The creep, tensile, and fatigue behavior of the single-crystal superalloys CMSX-2, AM1, and AM3 are investigated experimentally. Withdrawal-grown solution- and precipitation-treated specimens were subjected to constant-load stress-rupture tests at 760-1050 C, tensile tests at 25-950 C, low-cycle fatigue tests at 650 and 950 C, and high-cycle fatigue tests at 870 C; the results are presented graphically and discussed in detail. It is found that

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creep resistance in these alloys depends strongly on crystal orientation and the size and morphology of the gamma-prime precipitates, with anisotropy even at high temperatures. Plastic instabilities leading to localized deformation are seen at 25-650 C (of concern in the root of a turbine blade). Hot isostatic pressing or high-gradient solidification are recommended to increase the fatigue strength. T.K.

### A90-25340# DEVELOPMENT OF A NEW NICKEL BASED SINGLE CRYSTAL TURBINE BLADE ALLOY FOR VERY HIGH TEMPERATURES

T. KHAN and P. CARON (ONERA, Chatillon-sous-Bagneux, France) (European Conference and Advanced Materials and Processes, Aachen, Federal Republic of Germany, Nov. 22-24, 1989) ONERA, TP no. 1989-206, 1989, 7 p. refs (ONERA, TP NO. 1989-206)

The preparation and mechanical properties of MC2, an Ni-based single-crystal superalloy containing 8 wt pct Cr, 5 wt pct Co, 2 wt pct Mo, 5 wt pct Al, 2 wt pct Ti, and 6 wt pct Ta, are reported. Data from mechanical tests on withdrawal-solidified or microfused specimens before and after heat treatment at 1300 C are presented in tables and graphs, and micrographs illustrating the gamma-prime precipitate morphology are provided. MC2 is found to have a creep temperature more than 40 C higher than that of CMSX-2, along with 3-4 times longer low-cycle fatigue life at 760 C. No costly rhenium is required, and the alloy has a 30-C heat-treatment window which permits complete homogenization of the microstructure in a one-step heat treatment. T.K.

### A90-25356# BETA CEZ, A HIGH PERFORMANCE TITANIUM ALLOY FOR AEROSPACE ENGINES

B. PRANDI, E. ALHERITIERE (Compagnie Europeenne du Zirconium, Centre de Recherche, Ugine, France), F. SCHWARTZ (SNECMA, Direction Technique, Evry, France), and M. THOMAS (ONERA, Chatillon-sous-Bagneux, France) (Conference Internationale sur le Titane, 6th, Cannes, France, June 6-9, 1988) ONERA, TP no. 1990-8, 1990, 9 p. (ONERA, TP NO. 1990-8)

A new titanium alloy, beta CEZ, characterized by high tensile strength and high creep resistance at temperatures up to 450 C, has been developed for aeronautical turbine disk applications. Results obtained for the first 1.5-ton industrial ingots are promising, but the characteristics of full-size components and some important properties, such as fatigue resistance, have yet to be determined. The discussion covers alloy composition and the effects of different alloying elements (V, Mo, Fe, and Cr), the effect of forging parameters, and heat treatment optimization. V.L.

### A90-26865 METAL MATRIX COMPOSITES - READY FOR TAKE-OFF?

D. CHARLES (British Aerospace, PLC, Airbus Div., London, England) Metals and Materials (ISSN 0266-7185), vol. 6, Feb. 1990, p. 78-82. refs

Copyright

An evaluation is made of the development status, associated performance gains, and potential economic viability of the application of metal-matrix composite (MMC) materials to aircraft engines and airframes. Channel-section MMC extrusions used as electrical racking have already been shown to outperform both conventional Al alloy and CFRP alternatives, while yielding significant weight-savings over both alternatives. Attention is given to possible MMC applications in the National Aerospace Plane and various gas turbine engine components. The high cost of MMCs is identified as a continuing barrier to further market expansion. O.C.

### A90-27412 INTERSTITIAL MATERIALS FOR LOW THERMAL RESISTANCE JOINTS IN AVIONIC EQUIPMENT

HENRY A. RODDIGER and T. DEAN MOSBY (McDonnell Aircraft Co., Saint Louis, MO) SAE, Intersociety Conference on

Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 13 p.

(SAE PAPER 891441) Copyright

This paper discusses methods for improving thermal control by using interstitial materials (IMs) for low thermal resistance joints in avionic equipment. Several eutectic alloy IM concepts are described, including the improved thermal joint concept, a simplified thermal joint, the simple joint, the alloy joint, and the segmented-surface simple joint. Alternative concepts, using silicone elastomer materials or semisolid materials (Al/Ga) are discussed. The capabilities of IMs are compared, together with their disadvantages and concerns. I.S.

### A90-27597#

#### INDUSTRY TURNS TO CERAMIC COMPOSITES

JOSEPH CONSTANCE Aerospace America (ISSN 0740-722X), vol. 28, March 1990, p. 22-24, 26.

Copyright

Developments in the area of ceramic composites, which can be used to construct stronger, lighter weight, and more fuel-efficient aircraft, are examined. Ceramic composites are applicable aircraft braking systems, hypersonic fuselage skins, engine parts, and missile guidance fins. The production and testing of new ceramic composites are discussed. Consideration is given to the production of ceramic composites of an alumina or aluminum nitride matrix; developing glass ceramic matrix composites and silicon nitride matrix composites; and improving synthesis and processing technology to enhance the reliability of ceramic composites. I.F.

### A90-27598#

#### MATERIALS GET SMARTER

ALAN S. BROWN Aerospace America (ISSN 0740-722X), vol. 28, March 1990, p. 30-34, 36.

Copyright

The use of smart materials and structures in aircraft is discussed. The main functions of smart materials are: (1) on-line monitoring, (2) nondestructive evaluation, (3) vehicle health monitoring, and (4) flight control. The sensors for the smart structure are primarily fiber optic glass with polyimide coating. The advantages and disadvantages of electrorheological fluids, piezoelectric ceramics, and shape memory alloys as the actuators for smart structures are described. The development of a system to extract and interpret the data from the sensors is examined. I.F.

N90-16936# Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Systems and Logistics.

### THE FUTURE OF AIRCRAFT PAINT REMOVAL METHODS M.S. Thesis

MICHAEL J. THEN Sep. 1989 169 p  
(AD-A214946; AFIT/GLM/LSM/89S-67) Avail: NTIS HC A08/MF A01 CSCL 11/11

The purpose of this study was to develop a qualitative forecast for predicting aircraft paint removal methods. A Delphi methodology was used to create a technical forecast, combining the expectations of individuals who work with the related technologies on a daily basis. The Delphi results yielded five major conclusions. First, the projected paint removal method that will suit future paint removal needs is Plastic Media Blasting (PMB), and no other method is projected to be a serious threat to PMB's dominance. Second, PMB's process and parameters must be further researched to optimize the method's effectiveness. Third, the worker's safety can be further enhanced by both protective equipment that is available today, and facility construction that is specifically designed for the given removal method. Fourth, facility design is the major consideration when defining a paint removal's environmental effects. Lastly, it is undeterminable if robotics will replace human labor. Equipment that safely applies PMB is available today, while the equipment that further the method's effectiveness of separating heavy particles will be accessible in 1 year. GRA

**N90-16939#** Naval Submarine Medical Research Lab., Groton, CT. Dept. of Biomedical Sciences.

**ANALYSIS OF HYDRAULIC FLUIDS AND LUBRICATING OILS FOR THE FORMATION OF TRIMETHYLOLPROPANE PHOSPHATE (TMP-P) Final Report, Aug. 1985 - Apr. 1987**

A. B. CALLAHAN, D. V. TAPPAN, L. W. MOONEY, and E. HEYDER 9 Aug. 1989 97 p  
(AD-A215188; NSMRL-SP89-5) Avail: NTIS HC A05/MF A01 CSCL 06/11

Twenty-six different oils, hydraulic fluids and lubricants in U.S. Navy inventory were screened for yield of the neurotoxin Trimethylolpropane phosphate (TMP-P) in order to obtain an estimate of safety hazard potential. A commercially available synthetic aircraft engine oil (Exxon 2380) with a demonstrated yield of TMP-P was studied to establish the optimal temperature and pyrolysis time conditions for TMP-P production. Results of the analysis indicate that in the Exxon 2380 synthetic oil, TMP-P is formed very rapidly (within 5 minutes) with formation beginning in a temperature range of 350 to 400 C. The yield of TMP-P increases as a function of temperature and achieves a maximum yield at 450 to 500 C. Above this temperature, the TMP-P yield decreases rapidly to zero at 600 C probably due to thermal decomposition. Only one of the twenty-six oils from the U.S. Navy inventory gave evidence of TMP-P formation. The maximum TMP-P yield of oil (MIL-L-23699C) was only 1.9 percent (120 ug/g) of the maximum yield (6241 ug/g) for the Exxon 2380 synthetic engine oil. Results obtained from three laboratories have been applied to an assessment of the hazard potential of pyrolyzed oils and lubricants assayed in this study. GRA

**N90-16951#** Burns and Roe Services Corp., Pittsburgh, PA.  
**PRODUCTION OF JET FUELS FROM COAL DERIVED LIQUIDS. VOLUME 10: JET FUELS PRODUCTION BY-PRODUCTS, UTILITY, AND SULFUR EMISSIONS CONTROL INTEGRATION STUDY Interim Report, 1 May 1988 - 1 Apr. 1989**

R. J. ROSSI and D. A. HUBER Jun. 1989 109 p  
(Contract FY1455-86-N-0657; AF PROJ. 2480)  
(AD-A213872; AFWAL-TR-87-2042-VOL-10) Avail: NTIS HC A06/MF A01 CSCL 21/4

The potential of jet fuel production from the liquid by-product streams produced by the gasification of lignite at the Great Plains Gasification Plant (GPGP) in Beulah, North Dakota, was investigated. The results are reported of the effort by Burns and Roe Services Corporation/Science Applications International Corporation (BRSC/SAIC) to evaluate the impact of integrating Jet Fuel and/or Chemical Production Facilities with the Great Plains Gasification Plant. GRA

**N90-17825#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**INVESTIGATION OF THE FAILURE MODES IN A METAL MATRIX COMPOSITE UNDER THERMAL CYCLING M.S. Thesis**

PAUL G. ERMER Dec. 1989 135 p  
(AD-A216195; AFIT/GAE/ENY/89D-07) Avail: NTIS HC A07/MF A01 CSCL 11/4

There is currently wide interest in producing a vehicle capable of hypersonic flight. Structural materials in such a vehicle must be able to withstand high temperatures and retain high stiffness. Metal matrix composites (MMCs) are rapidly becoming the strongest candidates for these applications and concurrently, the need to study the effects of thermal cycling on them. This study emphasizes the development of a computer-controlled testing system that thermally fatigues a specimen under a variety of thermal conditions. A titanium matrix composite with silicon carbide fibers (SCS6/Ti-15-3) is the object of this study. To demonstrate the capability of this system, ten thermal fatigue tests were completed. The MMC was cycled from 300 F to 800 F while collecting strain and temperature data. A systematic study was undertaken to investigate the initiation and progression of the damage and its effect on mechanical properties as a function of applied thermal stresses. Results show that for up to 16,750 cycles, material

properties remain unchanged and do not correlate with thermal cycling. Interior damage begins at 500 cycles as deformation of the fiber/matrix interface. Exterior damage begins at 1,500 cycles as delamination cracks along the ply seams. GRA

**N90-17868\*#** Pratt and Whitney Aircraft, East Hartford, CT. Engineering Div.

**MATE (MATERIALS FOR ADVANCED TURBINE ENGINES) PROGRAM, PROJECT 3. VOLUME 2: DESIGN, FABRICATION AND EVALUATION OF AN OXIDE DISPERSION STRENGTHENED SHEET ALLOY COMBUSTOR LINER Final Report**

S. BOSE and K. D. SHEFFLER Feb. 1988 9 p  
(Contract NAS3-20072)  
(NASA-CR-180892; NAS 1.26:180892; PWA-5574-223-VOL-2)  
Avail: NTIS HC A02/MF A01 CSCL 11/6

The suitability of wrought oxide dispersion strengthened (ODS) superalloy sheet for gas turbine engine combustor applications was evaluated. Two yttria (Y<sub>2</sub>O<sub>3</sub>) dispersion strengthened alloys were evaluated; Incoloy MA956 and Haynes Development Alloy (HDA) 8077 (NiCrAl base). Preliminary tests showed both alloys to be potentially viable combustor materials, with neither alloy exhibiting a significant advantage over the other. MA956 was selected as the final alloy based on manufacturing reproducibility for evaluation as a burner liner. A hybrid PW2037 inner burner liner containing MA956 and Hastelloy X components and using a louvered configuration was designed and constructed. The louvered configuration was chosen because of field experience and compatibility with the bill of material PW2037 design. The simulated flight cycle for the ground based engine tests consisted of 4.5 min idle, 1.5 min takeoff and intermediate conditions in a PW2037 engine with average uncorrected combustor exit temperature of 1527 C. Post test evaluation consisting of visual observations and fluorescent penetrant inspections was conducted after 500 cycles of testing. No loss of integrity in the burner liner was shown. Author

**N90-17871#** Construcciones Aeronauticas S.A., Madrid (Spain). Subdireccion de Investigacion y Desarrollo de Tecnologia y Materiales.

**SIMPLE SHEAR TESTS OF THE FMI 23.5.06 ADHESIVE CURED AT LOW PRESSURE (12 PSI) [ENSAYOS DE CORTADURA SIMPLE DEL ADHESIVO FM123.5.06, CURADO A BAJA PRESION (12 PSI)]**

C. SERRANO 7 Nov. 1988 7 p In SPANISH  
(INFORME-I-298/88; ETN-90-96183) Avail: NTIS HC A02/MF A01

Specimens from a unidirectional carbon fiber bead panel used in aircrafts structures, adhesive bonded with the tested material, were tested after ultrasonic inspection. A large loss of shear resistance (93 percent) is found for specimens subjected to accelerated aging (temperature and humidity). ESA

**N90-17873#** Construcciones Aeronauticas S.A., Madrid (Spain). Subdireccion de Investigacion y Desarrollo de Tecnologia y Materiales.

**PRESSURE AIR TIGHTNESS TESTS OF LAMINATED PANELS FOR WING LEADING EDGE HEAT SHIELDS [ENSAYO DE ESTANQUEIDAD AL AIRE A PRESION DE PANELES LAMINADOS PARA HEAT SHIELD DE BORDE DE ATAQUE]**

B. SAINZ and A. BUENDIA 25 Jul. 1989 4 p In SPANISH  
(INFORME-I-377/89; ETN-90-96187) Avail: NTIS HC A01/MF A01

Preimpregnated laminates of glass fiber/phenolic resins were tested using 80 by 80 mm specimens of different ply composition and orientation. All tests show good air tightness up to 7 psi. ESA

## ENGINEERING

Includes engineering (general); communications; electronics and electrical engineering; fluid mechanics and heat transfer; instrumentation and photography; lasers and masers; mechanical engineering; quality assurance and reliability; and structural mechanics.

**A90-23792\*#** General Motors Corp., Indianapolis, IN.  
**AN EXPERIMENTAL STUDY OF TURBINE VANE HEAT TRANSFER WITH LEADING EDGE AND DOWNSTREAM FILM COOLING**

V. NIRMALAN and L. D. HYLTON (General Motors Corp., Allison Gas Turbine Div., Indianapolis, IN) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. refs  
 (Contract NAS3-24619)  
 (ASME PAPER 89-GT-69)

This paper presents the effects of downstream film cooling, with and without leading edge showerhead film cooling, on turbine-vane external heat transfer. Steady-state experimental measurements were made in a three-vane linear two-dimensional cascade. The principal independent parameters were maintained over ranges consistent with actual engine conditions. The test matrix was structured to provide an assessment of the independent influence of parameters of interest, namely, exit Mach number, exit Reynolds number, coolant-to-gas temperature ratio, and coolant-to-gas pressure ratio. The data obtained indicate that considerable cooling benefits can be achieved by utilizing downstream film cooling. The downstream film cooling process was shown to be a complex interaction of two competing mechanisms. The thermal dilution effect, associated with the injection of relatively cold fluid, results in a decrease in the heat transfer to the airfoil. Conversely, the turbulence augmentation, produced by the injection process, results in increased heat transfer to the airfoil. Author

**A90-23795#**  
**OPTIMUM WEIGHT DESIGN OF A ROTOR BEARING SYSTEM WITH DYNAMIC BEHAVIOR CONSTRAINTS**

TING NUNG SHIAU and JON LI HWANG (National Cheng Kung University, Tainan, Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 12 p. refs  
 (ASME PAPER 89-GT-74)

An efficient design algorithm for optimum weight design of a rotor bearing system with dynamic behavior constraints is investigated. The constraints include the restrictions on stresses, unbalance response, and/or critical speeds. The system dynamic behaviors are analyzed by the finite element method. And the exterior penalty function method is used as the optimization technique to minimize the system weight. The system design variables are the cross-sectional areas of the shaft and the stiffnesses of the bearings. The sensitivity analysis of the system parameters is also investigated. The example of a single spool rotor bearing system is employed to demonstrate the merits of the design algorithm with different combination of dynamic behavior constraints. At the optimum stage, it is shown that the weight of rotor system can be significantly reduced. Moreover, the optimum design weights are quite different for various combinations of dynamic behavior constraints. Author

**A90-23799#**  
**CASING VIBRATION AND GAS TURBINE OPERATING CONDITIONS**

K. MATHIOUDAKIS, E. LOUKIS, and K. D. PAPAILIOU (Athens, National Technical University, Greece) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8,

1989. 9 p. Research supported by the Hellenic General Secretariat for Research and Technology and EEC. refs  
 (ASME PAPER 89-GT-78)

The results from an experimental investigation of the compressor casing vibration of an industrial Gas Turbine are presented. It is demonstrated that statistical properties of acceleration signals can be linked with engine operating conditions. The power content of such signals is dominated by contributions originating from the stages of the compressor, while the contribution of the shaft excitation is secondary. Using non-parametric identification methods, accelerometer outputs are correlated to unsteady pressure measurements taken by fast response transducers at the inner surface of the compressor casing. The transfer functions allow reconstruction of unsteady pressure signal features from the accelerometer readings. A possibility is thus provided, for 'seeing' the unsteady pressure field of the rotor blades without actually penetrating through the casing, but by simply observing its external surface vibrations. Author

**A90-23801#**  
**EFFECT OF BLADE TIP CONFIGURATION ON TIP CLEARANCE LOSS OF A CENTRIFUGAL IMPELLER**

MASAHIRO ISHIDA, HIRONOBU UEKI (Nagasaki University, Japan), and YASUTOSHI SENOO (Miura Co., Ltd., Matsuyama, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 6 p.  
 (ASME PAPER 89-GT-80)

The effect of blade tip configuration on the tip clearance loss was examined experimentally using an unshrouded centrifugal impeller with backward-leaning blades. Tips with rounded edges, sharp square edges, and edges with end plates were tested. The observed tip clearance effects could be theoretically predicted by assuming reasonable values of the contraction coefficient  $\alpha = 0.91$  for the round edge, 0.73 for the sharp square edge, and 0.53 for the end-plate edge. The impeller efficiency was improved by about 1.5 point by reducing the contraction coefficient from 0.91 to 0.53. The effect of contraction coefficient on impeller efficiency depends on the ratio of leakage loss to the tip clearance loss. Improved efficiency for impellers with highly loaded blades is expected from reducing the contraction coefficient. C.D.

**A90-23802#**  
**SECONDARY FLOW DUE TO THE TIP CLEARANCE AT THE EXIT OF CENTRIFUGAL IMPELLERS**

MASAHIRO ISHIDA, HIRONOBU UEKI (Nagasaki University, Japan), and YASUTOSHI SENOO (Miura Co., Ltd., Matsuyama, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs  
 (ASME PAPER 89-GT-81)

The velocity distribution was measured at the exit of two different types of unshrouded centrifugal impellers under four different tip clearance conditions each; one with twenty radial blades and inducers and the other with sixteen backward-leaning blades. And the effect of tip clearance on input power was also measured. By increasing the tip clearance, the input power was hardly changed in the radial blade impeller and was reduced in the backward-leaning blade impeller. The velocity distribution normalized by the passage width between hub and shroud wall was hardly changed at the exit of the radial blade impeller by varying the tip clearance, on the other hand, the relative flow angle was reduced significantly and monotonously by an increase of tip clearance in the backward-leaning blade impeller. The change in input power due to the tip clearance was clearly related to the change of flow pattern at the exit of impeller due to the secondary flow, which is most likely caused by the component, normal to the blade, of the shear force to support the fluid in the clearance space against the pressure gradient in the meridional plane without blades. Author

**A90-23805#**  
**PRESSURE LOSS AND HEAT TRANSFER IN CHANNELS ROUGHENED ON TWO OPPOSED WALLS**

R. E. MAYLE (Rensselaer Polytechnic Institute, Troy, NY) ASME,



Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs  
(ASME PAPER 89-GT-86)

In order to selectively increase cooling effectiveness, coolant channels in gas turbine components are often only roughened on one or two walls of the channel. A model is presented for flow in rectangular channels having two opposed roughened walls and a theory is developed for both the pressure loss and heat transfer. The theory allows one to calculate the heat transfer coefficient on each wall separately in addition to the overall friction factor and heat transfer coefficient. Comparisons are made to data for similarly configured channels, tubes and surfaces roughened by regularly spaced transverse ribs placed normal to the flow direction. Correlations for the displacement velocity in the logarithmic law and the roughness Stanton number in terms of the rib pitch-to-height ratio and roughness Reynolds number are also presented. Author

#### A90-23806#

##### CHARACTERISTICS OF PARTIAL LENGTH CIRCULAR PIN FINS AS HEAT TRANSFER AUGMENTORS FOR AIRFOIL INTERNAL COOLING PASSAGES

S. C. ARORA and W. ABDEL-MESSEH (Pratt and Whitney Canada, Longueuil) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs  
(ASME PAPER 89-GT-87)

Pin fins are commonly used as heat transfer augmentors for internal cooling of turbine airfoils. These pins may extend from one wall to the other or may be segmented to meet specific requirements of removing the airfoil's varying heat load. Three configurations of the partial pins were tested in a 25:1 aspect ratio channel and the results are compared with those for the full pins. The array average heat transfer rate decreases linearly with increasing gap and is bounded by the value for full pins at one end and that for the smooth channel at the other. However, the local distribution of the Nusselt number and the average for each of the two walls depends on the configuration of the partial pins. The friction factor was lower for partial pins than for the full pins and also decreased with increasing gap. For the configuration with all partial pins on one wall, the friction factor was found to be the lowest with no change in the corresponding heat transfer rate from a wall with pins. Author

A90-23807\*# National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, AL.

##### PREDICTION OF THE AERODYNAMIC ENVIRONMENT AND HEAT TRANSFER FOR ROTOR-STATOR CONFIGURATIONS

L. W. GRIFFIN and H. V. MCCONNAUGHEY (NASA, Marshall Space Flight Center, Huntsville, AL) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. refs

(Contract NAS8-36284)

(ASME PAPER 89-GT-89)

A numerical study of the aerodynamic and thermal environment associated with axial turbine stages is presented. Computations were performed using a modification of the unsteady viscous code, ROTORI, and an improved version of the steady inviscid cascade system, MERIDL-TSONIC, coupled with boundary layer codes, BLAYER and STAN5. Two different turbine stages were analyzed: the first stage of the United Technologies Research Center Large Scale Rotating Rig (LSRR) and the first stage of the Space Shuttle Main Engine (SSME) high pressure fuel turbopump turbine. The time-averaged airfoil midspan pressure and heat transfer profiles were predicted for numerous thermal boundary conditions including adiabatic wall, prescribed surface temperature, and prescribed heat flux. Computed solutions are compared with each other and with experimental data in the case of the LSRR calculations. Modified ROTORI predictions of unsteady pressure envelopes and instantaneous contour plots are also presented. Relative merits of the two computational approaches are discussed. Author

#### A90-23812#

##### EFFECT OF RIB-ANGLE ORIENTATION ON LOCAL MASS TRANSFER DISTRIBUTION IN A THREE-PASS RIB-ROUGHENED CHANNEL

J. C. HAN and P. ZHANG (Texas A & M University, College Station) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs  
(Contract NSF CBT-87-13833)  
(ASME PAPER 89-GT-98)

The effect of rib-angle orientation on local mass transfer distributions in a three-pass square channel with a pair of opposite rib-roughened walls is investigated. The test section consisted of three straight square channels joined by two 180 degree turns, modeling the internal cooling passages of gas turbine airfoils. Naphthalene-coated ribs were attached to the top and the bottom walls of the naphthalene-coated, three-pass channel. The combined effects of the two sharp 180 degree turns and the rib orientations on the distributions of the local mass transfer coefficient in the entire three-pass channel were determined. Principal results are analyzed and determined for: (1) smooth channel, (2) ribbed channel, (3) comparison of 60 degree parallel ribs left direction to 90 degree transverse ribs, (4) angled ribs (5) combined effects of the sharp turn and rib-angle orientation, (6) heat transfer results for straight ribbed channels, (7) mass transfer coefficients between different ribs. R.E.P.

#### A90-23813#

##### HEAT TRANSFER AND PRESSURE DROP FOR SHORT PIN-FIN ARRAYS WITH PIN-ENDWALL FILLET

M. K. CHYU (Carnegie-Mellon University, Pittsburgh, PA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Research supported by Carnegie-Mellon University. refs  
(ASME PAPER 89-GT-99)

The effects of array configuration and pin-endwall fillet on the heat transfer and pressure drop of short pin-fin arrays are investigated experimentally. The arrays studied include an in-line and a staggered array, each having seven rows of five pins. One of the present results shows that the staggered array always has a higher array-averaged mass transfer coefficient than its in-line counterpart. However, the pressure drop for the staggered array is higher compared to the in-line configuration. These trends are unaffected by the existence of the pin-endwall fillet. Another significant finding is that an array with pin-endwall fillet generally produces lower heat transfer coefficient and higher pressure drop than that without endwall-fillet. This leads to the conclusion that pin-endwall fillet is undesirable for heat transfer augmentation. Author

#### A90-23818#

##### CURRENT STATUS OF CERAMIC GAS TURBINE R&D IN JAPAN

KIICHIRO YAMAGISHI, YUKIO YAMADA (MITI, Moonlight Project Promotion Office, Tokyo, Japan), YOSHIHIRO ECHIZENYA (New Energy and Industrial Technology Development Organization, Tokyo, Japan), and SHOJI ISHIWATA (Japan Automobile Research Institute, Inc., Tsukuba, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p.

(ASME PAPER 89-GT-114)

In 1988, Japan's Ministry of International Trade and Industry instituted two R&D projects for small-capacity (300 kW) ceramic-component gas turbines aimed at mobile power generation and cogeneration applications. Performance goals encompassed 42-percent higher thermal efficiency than current technology levels and turbine inlet temperatures of the order of 1350 C, in addition to reduced exhaust gas pollutant emissions. The development of a 100-kW automotive gas turbine making substantial use of ceramic components was also undertaken. A minimum ceramic component flexure strength of 400 MPa at 1500 C is required for the achievement of these performance goals. O.C.



**A90-23819#**

## **ADVANCED TURBINE TECHNOLOGY APPLICATIONS PROJECT (ATTAP) - OVERVIEW, STATUS, AND OUTLOOK**

PHILIP J. HALEY (General Motors Corp., Allison Gas Turbine Div., Indianapolis, IN) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Research sponsored by DOE.

(ASME PAPER 89-GT-118)

The ATTAP aims at proving the performance and life of structural ceramic components in the hot gas path of an automotive gas turbine engine. The program includes design, process development and fabrication, rig and engine testing, and iterative development of selected key ceramic components for the AGT-5 engine. A reference powertrain design based on this engine predicts acceleration driveability, and fuel economy characteristics exceeding those of current engines. Author

**A90-23825#**

## **THRESHOLD PERFORMANCE OPTIMIZATION OF A ROTOR-BEARING SYSTEM SUBJECTED TO LEAKAGE EXCITATION**

J. H. WANG (National Tsing Hua University, Hsinchu, Republic of China) and F. M. SHIH ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Sponsorship: National Science Council of the Republic of China. refs

(Contract NSC-77-0401-E007-17)

(ASME PAPER 89-GT-126)

The fluid leakage in shroud of the blades and the labyrinth seal of turbomachinery may induce instability and limit the output rating. In this work, the optimization technique has been used to find the diameters of shaft elements and the bearing supports so that the optimized rotor-bearing system can sustain larger fluid leakage force. The results show that the threshold performance of rotor-bearing systems can be significantly improved by slight modification of the shaft diameters. The results also indicate that the threshold performance can be improved more significantly by the combination of optimum bearing supports and optimum shaft diameters. Author

**A90-23827\*#** Cleveland State Univ., OH.

## **NONINTERACTIVE MACROSCOPIC RELIABILITY MODEL FOR CERAMIC MATRIX COMPOSITES WITH ORTHOTROPIC MATERIAL SYMMETRY**

STEPHEN F. DUFFY (Cleveland State University, OH) and JANE M. MANDERSCHIED (NASA, Lewis Research Center, Cleveland, OH) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. Previously announced in STAR as N89-15437. refs

(Contract NCC3-81)

(ASME PAPER 89-GT-129)

A macroscopic noninteractive reliability model for ceramic matrix composites is presented. The model is multiaxial and applicable to composites that can be characterized as orthotropic. Tensorial invariant theory is used to create an integrity basis with invariants that correspond to physical mechanisms related to fracture. This integrity basis is then used to construct a failure function per unit volume (or area) of material. It is assumed that the overall strength of the composite is governed by weakest link theory. This leads to a Weibull type model similar in nature to the principle of independent action (PIA) model for isotropic monolithic ceramics. An experimental program to obtain model parameters is briefly discussed. In addition, qualitative features of the model are illustrated by presenting reliability surfaces for various model parameters. Author

**A90-23828\*#** General Electric Co., Cincinnati, OH.

## **APPLICATION OF HOST TECHNOLOGY TO THE SSME HPFTP BLADE**

R. L. MCKNIGHT, T. S. COOK, G. S. BECHTEL, and H. T. HUANG (General Electric Co., Cincinnati, OH) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8,

1989. 12 p. refs

(Contract NAS3-24861)

(ASME PAPER 89-GT-130)

The development of turbine blade analysis tools as they moved from research contracts under the NASA HOST (Hot Section Technology) program to a PC-based system for preliminary design and to use in evaluating the SSME HPFTP (Space Shuttle Main Engine High Pressure Fuel Turbo Pump) blade is discussed. The heat transfer and structural analysis of the blade, the development of a data base for constitutive modeling of the blade materials, including coatings, and the use of advanced nonlinear finite element methods are addressed. C.D.

**A90-23834#**

## **A THREE DIMENSIONAL INVERSE METHOD IN TURBOMACHINERY. II - EXPERIMENTAL VERIFICATION**

JOAO EDUARDO BORGES (Instituto Superior Tecnico, Lisbon, Portugal) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. Research supported by the Holset Engineering Co., Ltd., Churchill College, and Junta Nacional de Investigacao Cientifica e Tecnologica. refs

(ASME PAPER 89-GT-137)

An experimental evaluation is conducted for a low-speed radial-inflow turbine rotor designed on the basis of a three-dimensional inverse method; the performance data obtained are compared with that of a comparable rotor designed by conventional methods. The novel design is found to have a peak total-to-static efficiency which is 1.4 percent superior to the conventional rotor. The rotor loss of the new design is also substantially lower than the conventional, indicating the importance of a fully three-dimensional inverse method's use in turbomachine design. O.C.

**A90-23843#**

## **LASER TRANSIT ANEMOMETRY INVESTIGATION OF A HIGH SPEED CENTRIFUGAL COMPRESSOR**

DAVID JAPIKSE and DAVID M. KARON (Concepts ETI, Inc., Wilder, VT) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs

(ASME PAPER 89-GT-155)

A detailed experimental investigation of a small centrifugal compressor stage has been completed using laser transit anemometry. Measurements at the inlet and discharge of an impeller have been made while recording data relative to a blade passage. Classical primary and secondary flow regimes within the rotor have been shown plus several compact 'cell-like' regions. Various components of velocity and turbulence intensity are presented. This study has demonstrated the capability of using the laser transit anemometer for investigating the kinematics of small, high speed turbomachinery components. Author

**A90-23848#**

## **MATHEMATICAL FORMULATION OF BLADE SURFACES IN TURBOMACHINERY. I - THEORETICAL SURFACE FORMULATIONS**

M. RAUTENBERG, A. ENGEDA (Hannover, Universitaet, Hanover, Federal Republic of Germany), and W. WITTEKINDT (Klein, Schanzlin und Becker AG, Bremen, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p.

(ASME PAPER 89-GT-160)

A simple, efficient method is presented for the definition of turbomachine blade surface contours which is germane to numerically controlled milling fabrication applications. The requirement of 'straight line' (elliptical, parabolic and hyperbolic cylinders, the elliptic cone, and the hyperbolic paraboloid) surface structures for milling operations is the basis of this mathematical treatment of contours, which is presently illustrated for the cases of a centrifugal compressor impeller, a mixed-flow pump impeller, and a gas turbine blade. O.C.

**A90-23849#****MATHEMATICAL FORMULATION OF BLADE SURFACES IN TURBOMACHINERY. II - PRACTICAL EXAMPLES OF DETERMINED SURFACES**

M. RAUTENBERG, A. ENGEDA (Hannover, Universitaet, Hanover, Federal Republic of Germany), and W. WITTEKINDT (Klein, Schanzlin und Becker AG, Bremen, Federal Republic of Germany) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. (ASME PAPER 89-GT-161)

'Straight-line surface' turbomachine blading mathematical structures previously devised with a view to a maximization of compatibility with, and implementability on, numerically controlled milling machines, have been used on the blade surfaces of (1) a centrifugal impeller, (2) a mixed-flow impeller, and (3) an axial-flow gas turbine rotor. The accuracies achieved, and the flexibility of the method, are found to be sufficient to prompt further expansion of the methodology to encompass all types of turbomechanical components. O.C.

**A90-23855#****INJECTION MOLDING DEVELOPMENT OF CERAMIC TURBINE COMPONENTS**

R. W. OHNSORG, M. O. TEN EYCK (Carborundum Co., Niagara Falls, NY), W. D. FRIEDMAN, P. ENGLER, G. J. HAVRILLA (BP America, Warrensville, OH) et al. ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. Research supported by DOE. (ASME PAPER 89-GT-170)

The AGT 101 automotive gas turbine development program has resorted to the injection molding of alpha-SiC turbine components due to its high volume production/near-net shape capabilities. Mold design is a critical consideration in internal flow minimization, together with injection molding control variables. Statistically-designed experiments were conducted to isolate the control variables influencing component quality; flow modeling was used to optimize specific molding variables which would minimize pressure, shear rate, and shear stress gradients. O.C.

**A90-23858#****AERODYNAMIC AND TORQUE CHARACTERISTICS OF ENCLOSED CO/COUNTER ROTATING DISKS**

W. A. DANIELS, B. V. JOHNSON (United Technologies Research Center, East Hartford, CT), and D. J. GRABER (United Technologies Corp., Engineering Div., West Palm Beach, FL) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 10 p. refs (Contract F33615-83-C-2331) (ASME PAPER 89-GT-177)

Experiments were conducted to determine the aerodynamic and torque characteristics of adjacent rotating disks enclosed in a shroud, in order to obtain an extended data base for advanced turbine designs such as the counterrotating turbine. Torque measurements were obtained on both disks in the rotating frame of reference for corotating, counterrotating and one-rotating/one-static disk conditions. The disk models used in the experiments included disks with typical smooth turbine geometry, disks with bolts, disks with bolts and partial bolt covers, and flat disks. A windage diaphragm was installed at mid-cavity for some experiments. The experiments were conducted with various amounts of coolant throughflow injected into the disk cavity from the disk hub or from the disk OD with swirl. The experiments were conducted at disk tangential Reynolds number up to  $1.6 \times 10^6$  to the 7th with air as the working fluid. The results of this investigation indicated that the static shroud contributes a significant amount to the total friction within the disk system; the torque on counterrotating disks is essentially independent of coolant flow total rate, flow direction, and tangential Reynolds number over the range of conditions tested; and a static windage diaphragm reduces disk friction in counterrotating disk systems. Author

**A90-23859#****A THEORETICAL STUDY OF INGRESS FOR SHROUDED ROTATING DISC SYSTEMS WITH RADIAL OUTFLOW**

JOHN W. CHEW (Rolls-Royce, PLC, Derby, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs (ASME PAPER 89-GT-178)

Sealing of the cavity formed between a stationary disk and a rotating disk under axisymmetric conditions is considered. A mathematical model of the flow in the cavity based on momentum integral methods is described. This model is coupled to a simple model of the seal for the case when no ingress occurs. Predictions of the minimum imposed flow required to prevent ingress are obtained and shown to be in reasonable agreement with the data of Bayley and Owen (1970), Owen and Phadke (1982), Phadke (1982), and Phadke and Owen (1982, 1983, 1988). With an empirical constant in the model chosen to match this data, predictions for the minimum sealing flow are shown to be in good agreement with measurements of Graber et al. (1987). The analysis of Phadke's data indicates that the measurements for small seal clearances must be viewed with caution due to errors in setting the seal clearance. These errors are estimated to be twice the minimum clearance considered. Seal behavior when ingress occurs is considered, and estimates of the amount of ingress are made from the available data. Author

**A90-23863#****AN ANALYSIS METHODOLOGY FOR INTERNAL SWIRLING FLOW SYSTEMS WITH A ROTATING WALL**

M. WILLIAMS, W. C. CHEN, G. BACHE, and A. EASTLAND (Rockwell International Corp., Rocketdyne Div., Canoga Park, CA) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. refs (ASME PAPER 89-GT-185)

A Navier-Stokes analysis methodology for calculating the flow through internal flow components with a rotating wall is developed. A novel treatment for the swirl coupling source terms is used to improve equation convergence. Johnston's secant approximation is used to formulate a three-dimensional law of the wall. The methodology is applied to three swirling flow systems and good agreement is found between the calculation results and experimental findings. C.D.

**A90-23865#****AN EXPERIMENTAL STUDY OF HEAT TRANSFER AND FILM COOLING ON LOW ASPECT RATIO TURBINE NOZZLES**

K. TAKEISHI, M. MATSUURA, S. AOKI, and T. SATO (Mitsubishi Heavy Industries, Ltd., Takasago, Japan) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. refs (ASME PAPER 89-GT-187)

The effects of the three-dimensional flow field on the heat transfer and the film cooling on the endwall, suction and pressure surface of an airfoil were studied using a low speed, fully annular, low aspect  $h/c = 0.5$  vane cascade. The predominant effects that the horseshoe vortex, secondary flow, and nozzle wake increases in the heat transfer and decreases in the film cooling on the suction vane surface and the endwall were clearly demonstrated. In addition, it was demonstrated that secondary flow has little effect on the pressure surface. Pertinent flow visualization of the flow passage was also carried out for better understanding of these complex phenomena. Heat transfer and film cooling on the fully annular vane passage surface is discussed. Author

**A90-23866#****IMPINGEMENT/EFFUSION COOLING - THE INFLUENCE OF THE NUMBER OF IMPINGEMENT HOLES AND PRESSURE LOSS ON THE HEAT TRANSFER COEFFICIENT**

A. M. AL DABAGH, G. E. ANDREWS, R. A. A. ABDUL HUSAIN, C. I. HUSAIN, A. NAZARI (Leeds, University, England) et al. ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto,

Canada, June 4-8, 1989. 12 p. refs  
(Contract SERC-GR/D/53029)  
(ASME PAPER 89-GT-188)

Measurement of the overall heat transfer coefficient within an impingement/effusion cooled wall are presented. The FLUENT CFD computer code has been applied to the internal aerodynamics to demonstrate the importance of the internal recirculation in the impingement gap. The influence of the relative pressure loss or hole pitch/hole internal decimeter (X/D) ratio between the impingement and effusion was investigated, for an effusion X/D of 4.67 and an impingement gap (Z) of 8 mm, and shown to be only significant at high value of coolant mass flow per unit wall area (G) where a reduction in surface averaged convective heat transfer coefficient (h) of 20 percent occurred. Increasing the number of holes, N, in the impingement/effusion array at a constant Z of 8 mm reduced h by 20 percent, mainly due to the higher Z/D for the smaller holes at high N. Reduced numbers of impingement holes relative to the effusion holes, in a ratio of 1 to 4, were shown to have a small influence on h with a maximum reduction in h of 20 percent at high G and a negligible effect at low G. Author

### **A90-23867# EFFECTS OF AN EMBEDDED VORTEX ON INJECTANT FROM A SINGLE FILM-COOLING HOLE IN A TURBULENT BOUNDARY LAYER**

P. M. LIGRANI (U.S. Naval Postgraduate School, Monterey, CA) and W. WILLIAMS ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by USAF. refs  
(ASME PAPER 89-GT-189)

Effects of embedded longitudinal vortices on heat transfer in turbulent boundary layers with injection from a single film cooling hole are described. These results were obtained at a freestream velocity of 10 m/s, with a film cooling hole inclined 30 degrees to horizontal and a blowing ratio of about 0.50. The ratio of vortex core diameter to injection hole diameter was 2.14, and the ratio of circulation to injection velocity times hole diameter was about 2.8. Coolant distributions and spatially resolved heat transfer measurements indicate that injection hole centerlines must be at least 2.0 - 2.5 vortex core diameters away from the vortex center in the lateral direction to avoid significant alterations to wall heat transfer and distributions of film coolant. Under these circumstances, protection from film cooling is evident at least up to 55 hole diameters downstream of injection. When the injection hole is closer to the vortex center, secondary flows convect most injectant into the vortex upwash and thermal protection from film cooling is destroyed for streamwise locations from the injection hole greater than 17.5 hole diameters. Author

### **A90-23868# AERODYNAMICS OF COOLING JETS INTRODUCED IN THE SECONDARY FLOW OF A LOW SPEED TURBINE CASCADE**

F. BARIO, F. LEOUEUF, A. ONVANI, and A. SEDDINI (Lyon, Ecole Centrale, Ecully, France) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 9 p. Research supported by DRET and Metraflu. refs  
(ASME PAPER 89-GT-192)

The aerodynamic behavior of cold discrete jets in a cold secondary flow is investigated. Configurations including single jets and rows of jets are studied. These jets are introduced through the side wall of a low speed nozzle turbine cascade. The experimental set up and the jet behavior are fully described. The effects of location with respect to the blades, mass flow ratio, yaw and incidence angles on the aerodynamics of single jets are investigated. The influence of neighboring jets is detailed in the case of multiple jet configurations. The interaction with the secondary flow is presented. The local pressure and velocity fields, trajectories and visualizations are discussed. The measuring apparatus includes a five hole probe and an hot wire for intermittency measurements. Author

### **A90-23870#**

#### **EXPERIMENTAL INVESTIGATION INTO THE EFFECTS OF ROTATING AND STATIC BOLTS ON BOTH WINDAGE HEATING AND LOCAL HEAT TRANSFER COEFFICIENTS IN A ROTOR/STATOR CAVITY**

J. A. MILLWARD and P. H. ROBINSON (Rolls-Royce, PLC, Derby, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by the Ministry of Defence Procurement Executive. refs  
(ASME PAPER 89-GT-196)

Experiments are carried out on the following combinations of bolts: single row rotating, single row static, double row rotating, and combined rotating and static. Different sizes of bolts were tested as well as variation in pitching and the effects of various bolt shields. The adiabatic wall temperature was measured locally at various positions on the rotor surface both between adjacent bolts and at different pitch circle diameters. In the course of the testing, a considerable reduction in windage due to the shape of the disc surface near the rim was measured. This study describes the experimental technique used and presents a selection of the windage and heat transfer results. R.E.P.

### **A90-23872#**

#### **SIMULATION OF COOLING FILM DENSITY RATIOS IN A MASS TRANSFER TECHNIQUE**

H. D. AMMARI, N. HAY, and D. LAMPARD (Nottingham, University, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs  
(ASME PAPER 89-GT-200)

A systematic investigation of the influence of molecular Schmidt number on cooling film mass transfer coefficient has been conducted using a swollen-polymer technique and laser holographic interferometry. A variation in Schmidt number by about 28 percent was accomplished by an injection of a foreign gas and gas mixtures through a single normal hole at a blowing rate of one. The experiments were performed at a constant temperature in a subsonic, zero mainstream pressure gradient turbulent boundary layer on a flat plate. The experimental results indicate that Schmidt number has a negligible effect on cooling film mass transfer coefficient within the range examined. Consequently, measurement of cooling film mass transfer coefficients at nonunity density ratios using a mass transfer method with foreign gas injection is experimentally validated. Author

### **A90-23881#**

#### **POWER DISSIPATION IN SMOOTH AND HONEYCOMB LABYRINTH SEALS**

W. F. MCGREEHAN (GE Aircraft Engines, Cincinnati, OH) and S. H. KO (Texas A & M University, College Station) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 11 p. Research supported by GE Aircraft Engines. refs

(Contract F33657-83-C-0100)

(ASME PAPER 89-GT-220)

The surface frictional characteristics of a labyrinth seal can result in significant windage power dissipation for high speed seals. Recent advances in seal design have produced high speed, high pressure labyrinth seals which operate at very low leakage rates. The reduced leakage is beneficial to gas turbine efficiency, but seal discharge temperatures can approach material design limits with high windage power dissipation. Also, a high air temperature rise can influence seal leakage flow. Consequently, the general assumption of negligible rotational effect on leakage is not always valid. A method is presented for the prediction of seal power dissipation and leakage flow over a wide range of design parameters. Results are compared to available test data and several approaches examined for the reduction of seal windage. Author

### **A90-23882#**

#### **THE PREDICTION OF BOUNDARY LAYERS WITH ROTATION AND VARIATION OF STREAM FILAMENT THICKNESS**

YAONAN HUA and BAOGUO WANG (Chinese Academy of Sciences, Institute of Engineering Thermophysics, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs (ASME PAPER 89-GT-227)

Boundary layer equations with allowance for the rotation and variation of stream filament thickness on the stream surface of revolution in turbomachinery are derived. A method is presented for calculating laminar, turbulent, and wake boundary layers by means of solving the integral momentum equation. The turbulent boundary layer with separation also can be calculated by use of present method. Author

#### A90-23885#

##### A SIMPLIFIED MODEL FOR UNSTABLE TEMPERATURE FIELD CALCULATION OF GAS TURBINE ROTOR

GUANGXIN HE (Tsinghua University, Beijing, People's Republic of China) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p. (ASME PAPER 89-GT-234)

A simplified model is presented for calculating the unstable temperature field of a cooled turbine rotor by the finite element method. In the simplified model, an outer radius for calculating has been chosen which is smaller than the radius of the fir-tree root groove's bottom. And an equivalent heat release coefficient has been introduced. Thus, the calculation can be treated as an axial symmetrical problem and carried out on a microcomputer. The simplified model has been used to calculate the unstable temperature field during the start-up of a rotor. A comparison with the three-dimensional calculated result shows that the simplified model is satisfactory. Author

#### A90-23891#

##### HOLOGRAPHIC FLOW VISUALISATION OF TURBOFAN BY-PASS AND CORE NOZZLE STREAMS

P. J. BRYANSTON-CROSS (Warwick, University, Coventry, England), A. E. HARRIS, and S. BAKSHI (Aircraft Research Association, Ltd., Bedford, England) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 8 p. refs (ASME PAPER 89-GT-260)

This investigation has been made to show the suitability of holography as an optical flow diagnostic for turbofan nozzle flow structures. In this case a static 1/25th scale model of a powered turbofan nacelle has been used for nacelle/wing integration studies and evaluated using a holographic technique. The holograms made show the core jet and the by-pass flow as it emerges from the nacelle nozzle system. They also show evidence of structural vibration at the by-pass nozzle wall. A comparison has also been made with alternative non-invasive diagnostic techniques. Author

#### A90-23900#

##### AN ULTRASONIC FATIGUE FACILITY FOR HCF/LCF INTERACTIVE TESTS

J. DROSSIS (Atomic Energy of Canada, Ltd., Mississauga), D. MCCAMMOND, A. N. SINCLAIR (Toronto, University, Canada), and C. YEUNG (Canadair, Ltd., Montreal, Canada) Canadian Aeronautics and Space Journal (ISSN 0008-2821), vol. 35, Dec. 1989, p. 211-217. Research supported by Pratt and Whitney Canada and NSERC. refs

This loading spectrum experienced by fan and axial compressor blades consists of very high frequency stresses from blade vibrations combined with the centrifugal stresses generated by throttle excursions. The interaction between these two fatigue regimes, high cycle fatigue (HCF) and low cycle fatigue (LCF), respectively, is of importance in a number of areas in the aerospace industry. This paper describes the design and commissioning of an experimental fatigue facility to examine HCF/LCF interaction where the HCF frequency is in the kHz range. This has considerable advantage in testing times over conventional fatigue facilities which operate at frequencies less than 100 Hz, and can more realistically reflect the service frequencies experienced from compressor blade vibrations. Author

#### A90-23904

##### PARABOLIC FLIGHT EXPERIMENTS ON FLUID SURFACES AND WETTING

D. LANGBEIN (Battelle-Institut, Frankfurt am Main, Federal Republic of Germany), R. GROSSBACH, and W. HEIDE Applied Microgravity Technology (ISSN 0931-9530), vol. 2, Feb. 1990, p. 198-211. refs (Contract BMFT-QV-8723)

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During parabolic flights of a KC-135 aircraft, experiments were performed on the behaviors of water, glycerine, and Fluorinert in different containers. Results are presented from studies of liquid menisci in solid edges, the formation of solid edges with differing dihedral angles using arrays of microscope slides and rosette modules, the spreading of water and glycerine in rosette modules, and wetting dynamics. Other studies include contact angles in reduced gravity, liquid menisci in prisms, spreading and breakage in rhombic prisms and circular cylinders, liquid rings around conical rods, and wetting of a cylindrical annulus and close-packed spheres. R.B.

#### A90-23953

##### NONLINEAR RESPONSE AND FATIGUE OF STIFFENED PANELS

SIU-TONG CHOI (Weidinger Associates Consulting Engineers, New York) and RIMAS VAICAITIS (Columbia University, New York) Probabilistic Engineering Mechanics (ISSN 0266-8920), vol. 4, Sept. 1989, p. 150-160. refs

Copyright

The surface protection systems of aerospace and aircraft structures are often constructed from discretely stiffened panels. The information that is available indicates that response of surface panels exposed to high intensity surface flow and/or acoustic pressure is nonlinear. A theoretical study on nonlinear response of discretely stiffened panels to random pressures and thermal loads is presented in this paper. The random pressures are simulated in time-space domain and the nonlinear equations of motion are solved numerically by a Monte Carlo type approach. In addition, preliminary estimates of sonic fatigue based on the nonlinear stress distribution of response peaks and fatigue data from constant amplitude tests are given. The numerical results include deflection and stress response time histories, spectral densities, root mean square values, crossing rates, probability distribution, peak distribution and fatigue damage. Author

#### A90-24087

##### TESTING OF STATISTICAL HYPOTHESES AND DERIVATION OF CONFIDENCE INTERVALS FROM INSPECTION DATA SAMPLES [PROVERKA STATISTICHESKIH GIPOTEZ I POSTROENIE DOVERITEL'NYKH INTERVALOV PO VYBOROCHNYM DANNYM TIPA OSMOTROV]

A. A. BELAICHUK TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 87-97. In Russian. refs

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An attempt is made to apply the likelihood ratio criterion to integrity inspection data for airframe structures. By using the Monte Carlo method, it is shown that the likelihood ratio criterion provides better results than the criterion based on the asymptotic normality of maximum likelihood estimates. Based on the likelihood ratio criterion, procedures are developed for testing hypotheses and deriving confidence intervals which make it possible to improve the reliability of service data analysis. V.L.

#### A90-24092

##### EFFICIENT STRUCTURAL MATERIAL DISTRIBUTION IN THE MAIN FRAME OF A FLIGHT VEHICLE [RATSIONAL'NOE RASPREDELENIE KONSTRUKTSIONNOGO MATERIALA V SILOVOM SHPANGOUTE LETATEL'NOGO APPARATA]

V. V. SAURIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 1, 1988, p. 125-129. In Russian.

Copyright

A method for optimizing structural material distribution in the main frame of a flight vehicle is proposed, and calculation results

are presented. Some design features are identified which have a positive effect on the mass characteristics of the structure. Parametric dependences of the structure weight on the geometrical parameters of the frame are presented. V.L.

**A90-24102****EFFECT OF CREEP ON THE LOAD-BEARING CAPACITY OF COMPRESSED PANELS [VLIANIE POLZUCHESTI NA NESUSHCHUIU SPOSOBNOST' SZHATYKH PANELEI]**

I. I. POSPELOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 85-92. In Russian.

Copyright

The problem of calculating the load-bearing capacity of compressed panels with allowance made for creep is formulated and solved. A criterion is given for estimating the load-bearing capacity of the wing panels of a supersonic passenger aircraft. The role of temperature and Mach number in reducing the load-bearing capacity of panels is investigated for chosen values of operational loads. B.J.

**A90-24112****AEROELASTIC DEFORMATION OF A CRESCENT-SHAPED RIGID SUPPORT IN THE DIFFUSER CHAMBER OF A WIND TUNNEL [AEROUPRUGAIA DEFORMATSIYA SERPOVIDNOI ZHESTKOI STOIKI, RASPOLOZHENNOI V KAMERE STVOROK DIFFUZORA AERODINAMICHESKOI TRUBY]**

A. V. PILIUGIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 75-86. In Russian.

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The elastic interaction between a crescent-shaped rigid support in the diffuser chamber of a wind tunnel and subsonic aerodynamic flow is investigated analytically in the context of linear nonviscous flow theory. The approach used here, which is based on an exact analytical solution, allows quick and efficient multiparametric numerical analysis of the structural features of the mount with allowance for the interference of the adjacent sections of the wind tunnel. The method may be useful in developing wind tunnel experiments and in wind tunnel design. V.L.

**A90-24118****AUTOMATION OF THE DEVELOPMENT OF A FINITE ELEMENT MODEL FOR SHELLS OF THE WING TYPE [AVTOMATIZATSIIA POSTROENIIA KONECHNO-ELEMENTNOI MODELI DLIYA OBOLOCHEK TIPY KRYLA]**

A. K. KOVALEVSKII TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 115-119. In Russian. refs

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An approach is proposed for automating the development of a finite element model for an aircraft wing representing a shell reinforced by a frame. It is assumed that the surface of the structure is linear and can be described geometrically on the basis of the initial aerodynamic profiles of the wing specified in three-dimensional Cartesian coordinates. The procedure involves determining the nodes of the calculation grid, assigning numbers to the nodes, and constructing an index matrix describing topological relations between the finite elements through the grid node numbers. V.L.

**A90-24134****DETERMINATION OF THE TORSION RIGIDITY OF A MULTIPLE-RIB TORSION BOX OF AN AIRCRAFT LIFTING SURFACE [OPREDELENIE ZHESTKOSTI NA KRUCHENIE SILOVOGO KESSONA MNOGONERVIURNOI KONSTRUKTSII NESUSHCHEI POVERKHNOSTI LETATEL'NOGO APPARATA]**

E. K. LIPIN and V. E. TENIAEVA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 128-134. In Russian.

Copyright

The paper examines the problem of determining the effective torsion rigidity (TR) of the torsion box of a lifting surface. The TR of the root section of the box is determined by investigating the rigidity characteristics of calculation models of the torsion box in the form of a thin-wall beam, plate, and prismatic shell, and by

calculating the stress-strain state using the finite element method. B.J.

**A90-24145****ADVANTAGES OF FLOW VARIABLES IN THIN VISCOUS SHOCK LAYER PROBLEMS [O PREIMUSHCHESTVAKH POTOKOVYKH PEREMENNYKH V ZADACHE TONKOGO VIAZKOGO UDARNOGO SLOIA]**

A. L. ANKUDINOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 89-99. In Russian.

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A special form of equations of a three-dimensional thin viscous shock layer has been derived from the traditional form through the reduction of variables related for functions describing the flow (flow variables). It is shown that the system of shock layer equations using these variables has generally better stabilizing properties in a numerical solution. In degenerate cases (the two-dimensional case and the spread plane), the variables proposed here make it possible to formulate the initial problem as a purely boundary layer one. As an example, calculations are carried out for flow in the plane of symmetry of an elliptical hyperboloid and near a hyperboloid of revolution at angle of attack. V.L.

**A90-24153****A METHOD FOR DETERMINING EQUIVALENTS DURING THE FATIGUE TESTING OF STRUCTURES IN AN ACOUSTIC FIELD [METODIKA OPREDELENIYA EKIVALENTOV PRI ISPYTANIYAKH KONSTRUKTSII NA USTALOST' V AKUSTICHESKOM POLE]**

N. A. MOZZHEROVA TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 5, 1988, p. 155-160. In Russian.

Copyright

A method is described for determining the conditions of the fatigue testing of structures in an acoustic chamber that are equivalent to design conditions in terms of accumulated damage. The method is based on representing the response of a structure to acoustic loading as a sum of normal tones. The design acoustic load and the characteristic flight moments are treated as a piecewise stationary process with a given spectral density. It is shown that, in the general case, the duration of testing in the equivalent mode depends on both the design values of the load spectral density and the structure response spectrum during testing. V.L.

**A90-24162****MULTICRITERIAL OPTIMIZATION OF LUGS IN HINGE JOINTS [MNOGOTSELEVAIA OPTIMIZATSIIA PROUSHIN V SHARNIRNYKH UZLAKH]**

G. I. BRYZGALIN, V. M. VOLCHKOV, A. E. GODENKO, S. D. POZNYSHEV, and I. U. G. TARABRIN TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 6, 1988, p. 74-81. In Russian.

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An algorithm for the multicriterial optimization of hinge joint lugs in aircraft structures is proposed which is based on optimizing the 'overall quality' of the part. Particular design criteria include fatigue strength, mass (volume) of the part, loading, and stress concentration. The approach proposed here makes it possible to optimize a given part with respect to the parameters considered to be particularly important in a specific situation. Optimization of the geometric parameters of 10-70-mm-diameter lugs in a part of V95pchT2 aluminum alloy is examined as an example. V.L.

**A90-24293****DESIGN, REALIZATION, AND QUALIFICATION OF MODEL COMPOSITE ROTOR BLADES [CONCEPTION, REALISATION ET QUALIFICATION DE MAQUETTES DE PALES EN MATERIAUX COMPOSITES]**

P. DUPRIEZ, P. GEOFFROY, and B. PALUCH (ONERA, Lille, France) Revue Francaise de Mecanique (ISSN 0373-6601), no. 2, 1989, p. 229-241. In French. refs

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Techniques used at ONERA for the design and analytical evaluation of composite wind-tunnel models of flexible helicopter

rotor blades or propfan rotors are described and demonstrated. Topics addressed include the equations characterizing the static, fatigue, and dynamic properties of anisotropic composites; the formulation of a beam-type finite-element model; and procedures for monitoring the fabrication process and checking the finished product. Typical applications are shown in extensive diagrams, graphs, and photographs; the predictions of the FEM computations are found to be in good agreement with experimentally measured values. T.K.

#### A90-24353

##### **ISOTHERMAL VELOCITY AND TURBULENCE MEASUREMENTS DOWNSTREAM OF A MODEL MULTILOBED TURBOFAN MIXER**

P. KOUTMOS and J. J. MCGUIRK (Imperial College of Science, Technology, and Medicine, London, England) Experiments in Fluids (ISSN 0723-4864), vol. 8, no. 3-4, Dec. 1989, p. 183-191. Research supported by Rolls-Royce, PLC. refs Copyright

An isothermal experimental investigation of the three-dimensional flowfield downstream of a model multilobed turbofan forced mixer is presented. LDA measurements of the three mean velocities and corresponding turbulence intensities were obtained in the downstream duct where the turbine (primary) and fan (secondary) streams emerging from the lobes mix together. The flow development in the near field was quantified by measuring the cross-plane velocities. These were found to consist of large radial flows, of order 15 percent of the mean axial velocities at the lobe inlet, with changing sign depending on location. The cross-plane flow is consistent with a large-scale axial vortex pair (per lobe) which persists throughout the downstream duct and enhances mixing in this region. Author

#### A90-24376

##### **BUCKLING ANALYSIS OF FRP FACED CYLINDRICAL SANDWICH PANEL UNDER COMBINED LOADING**

KOGANTI MOHANA RAO (Indian Institute of Technology, Kharagpur, India) and H.-R. MEYER-PIENING (Zuerich, Eidgenossische Technische Hochschule, Zurich, Switzerland) Composite Structures (ISSN 0263-8223), vol. 14, no. 1, 1990, p. 15-34. refs Copyright

The buckling analysis of a simply supported fiber-reinforced plastic (FRP)-faced cylindrical anisotropic sandwich panel subjected to combined action of axial compression and bending and shear was carried out using the Rayleigh-Ritz method. Results indicate that the longitudinal buckling load in the presence of a small shear decreases with aspect ratio up to a certain value, and then increases, in contrast to the continuous increase in the case of a flat plate. The orientation of fibers at which the buckling load is maximal depends on the combinations of radius, aspect ratio, shear buckling coefficient, and bending load coefficient. It was found that, for panels of large curvature, the presence of numerically small negative shear load improves buckling strength, whereas for panels of low curvature and for flat panels, the presence of small positive shear is beneficial. I.S.

#### A90-24377

##### **POSTBUCKLING FINITE ELEMENT ANALYSIS OF COMPOSITE PANELS**

GOTTFRIED LASCHET and JEAN-PIERRE JEUNETTE (Liege, Universite de l'Etat, Belgium) Composite Structures (ISSN 0263-8223), vol. 14, no. 1, 1990, p. 35-48. Research supported by the Institut pour l'Encouragement de la Recherche Scientifique dans l'Industrie et l'Agriculture. refs Copyright

A three-dimensional degenerated isoparametric multilayer finite element is described in conjunction with an automatic incremental/iterative method to find the complete nonlinear response of arbitrarily laminated composite panels under destabilizing loads. In the prebuckling range of the structural response, incremental bifurcation analyses are combined with an arc-length algorithm to control the step size; for the postbuckling

path, the increment size is determined automatically by a new recurrence formula. The good behavior of this proposed procedure is illustrated on two structural applications, namely a thick hinged multilayer cylindrical shell subjected to a transverse load and a highly curved cylindrical composite panel under in-plane compression. Author

#### A90-24681

##### **STANDARDIZATION IN AEROSPACE PLATING AND COATING**

ARSHAD HAFEEZ (SAE, Inc., Warrendale, PA) SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 8 p. (SAE PAPER 890913) Copyright

In order to supply industry with standards in aerospace plating and coating to meet government specifications, the Plating and Coating Committee of the Society of Automotive Engineers developed or reviewed over 60 Aerospace Material Specifications (AMS) which cover plating, coating, anodic treatment, and chemical treatment processes. This paper describes the AMS quality control and processes document, which consists of eight sections: (1) Scope, (2) Applicable Documents, (3) Technical Requirements, (4) Quality Assurance Provisions, (5) Preparation for Delivery, (6) Acknowledgment, (7) Rejections, and (8) Notes. The existing document will be revised at least every five years, as new specifications will be written by users and suppliers. I.S.

#### A90-24691

##### **ROBOTIC DRY STRIPPING OF AIRFRAMES - PHASE II**

ROBERT A. PAULI (Pauli and Griffin Co., Vacaville, CA) and ART M. WITTENBERG (Air Canada, Quebec) SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 10 p. (SAE PAPER 890926) Copyright

This paper describes a program for the development of a dust-free closed-cycle robotic system for dry stripping of airframes, designed to insure dust-free work environment and reduce plastic-media loss, the contamination risk, and the media inventory requirement. Phase I of the program involved building a prototype of the proposed robotic arm and its dust enclosure to prove basic automation concepts, showing reasonable paint removal rate from a curved surface, and establishing that the process is dust-free and recovers plastic media in a closed-cycle fashion. This paper contains calculations on the effect of different blasting parameters in order to determine optimum values required for the completion of Phase I. Also presented is the progress achieved by the Phase II of the program, which is to prove the total concept by building the complete system and demonstrating its capability. I.S.

#### A90-24692

##### **TWO SPECIAL COST-EFFECTIVE APPLICATIONS FOR ELECTROCHEMICAL METALLIZING FOR IMPROVED BRAZING AND BONDING**

MARY RUBINSTEIN (Selectrons, Ltd., New York), JOHN LEMBO (Selectrons, Ltd., Waterbury, CT), and FRED SWARTLING (Metalize Texas, Bastrop) SAE, Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 13 p. (SAE PAPER 890927) Copyright

Two specialty applications for electrochemical metallizing and electrochemical anodizing are discussed. These uses are for improved brazing and bonding. Preparation procedures for the electrochemical metallizing and anodizing are described. Aircraft engine parts whose brazeability is improved using electrochemical metallizing include Hastelloy nozzle assemblies, Inconel support assemblies, Inconel turbine blades, and stainless steel rotor hubs. A chromic-type selective electrochemical anodizing of all leading edge surfaces prior to bonding is presently used in several aircraft shops, and some helicopter shops use selective electrochemical anodizing for touch-up and repair of bath-anodized surfaces. I.S.

#### A90-24702

##### **AUTOMATING AND CONTROLLING DRY PAINT STRIPPING**

F. R. CUNLIFFE, III (Aerolyte Systems, Burlingame, CA) SAE,

Annual Aerospace/Airline Plating and Metal Finishing Forum and Exposition, 25th, New Orleans, LA, Mar. 27-30, 1989. 11 p. (SAE PAPER 890939) Copyright

The key parameters which affect the efficiency and success of the dry paint-stripping process are discussed, including pressure at the nozzle, the size of the nozzle, the angle of blasting, the distance from the work-piece, the hardness and the size of the media, and the media flow. It is pointed out that, by automating the dry paint stripping process, many of these parameters can be controlled, making it possible to reproduce the same result, time and again. Attention is given to a recently developed automated aircraft wheel stripping machine, whose units are operated by joy stick controls from outside the cabinet. The wheel can be rotated and moved forward and backward in order to gain access to all of the surfaces; the operator also controls the nozzle manipulator which is a five-axis unit. At present, robotic systems are being developed for small aircraft and for the jumbo jets in use throughout the commercial airline fleets of the world. I.S.

#### A90-25108

##### **AEROELASTIC TAILORING OF A WING WITH COMPOSITE SKIN**

DE GUAN and KE ZHONG (Beijing University of Aeronautics and Astronautics, People's Republic of China) Chinese Journal of Aeronautics (ISSN 1000-9361), vol. 2, Nov. 1989, p. 271-276. Copyright

Preliminary results of aeroelastic tailoring of a wing of medium aspect ratio, medium sweepback angle constructed with composite skin and metal frames, is presented. The composite skin is modeled with quadrilateral plates of orthotropic material. Tsai-Hill failure theory is used in fully stressed design of the composite skin, and uniform derivative criteria are used in the optimization with respect to flutter speed and aileron effectiveness. R.E.P.

#### A90-25303#

##### **REVIEW OF COMPOSITE ROTOR BLADE MODELING**

DEWEY H. HODGES (Georgia Institute of Technology, Atlanta) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 561-565. refs (Contract DAAL03-88-C-0003) Copyright

The present evaluation of state-of-the-art modeling techniques for helicopter composite rotor blades having arbitrary cross-sections proceeds in view of the fact that a structural theory sufficiently general to treat the great variety of cross-sections, spanwise nonuniformities, and potentially large deflections, does not yet exist. Attention is given to remaining questions concerning the formulation of a one-dimensional beam theory with suitable kinematics and materials constants for composite rotor blades. O.C.

#### A90-25343#

##### **NEW METALLIC FELTS WITH IMPROVED RESISTANCE TO HIGH TEMPERATURE OXIDATION**

C. DELAUNAY, D. LOCQ, and A. WALDER (ONERA, Chatillon-sous-Bagneux, France) (EUROMAT 89, Meeting, Aachen, Federal Republic of Germany, Nov. 22-24, 1989) ONERA, TP no. 1989-210, 1989, 7 p. refs (ONERA, TP NO. 1989-210)

The fabrication and properties of metallic felts based on melt-spun MCrAlY fibers and characterized by high-temperature oxidation resistance are briefly described. The sintering of the fibers in a halogenous gas phase results in high porosity (over 95 percent), which can be reduced by pressing. The felts, originally developed for turboengine abradable seals, can also be used in catalytic converters for motor vehicles and as high-temperature dust filters. V.L.

#### A90-25602#

##### **CRL'S MOBILE SATELLITE COMMUNICATION EXPERIMENTS USING ETS-V**

K. KONDO, R. SUZUKI, Y. HASHIMOTO, Y. MATSUMOTO, T. IDE (Communications Research Laboratory, Koganei, Japan) et al. IN: AIAA International Communication Satellite Systems

Conference and Exhibit, 13th, Los Angeles, CA, Mar. 11-15, 1990, Technical Papers. Part 1. Washington, DC, American Institute of Aeronautics and Astronautics, 1990, p. 1-7. refs (AIAA PAPER 90-0775) Copyright

Japanese ETS-V realized experimental mobile satellite communication system. CRL is conducting several types of mobile communication experiments with aircraft, ships, and land mobile terminals including a portable message communicator. The digital or analog voice, data, and FAX signals are successfully transmitted with many newly developed technologies such as a phased-array antenna for aircraft, a digital land mobile terminal, a fading reduction antenna for ships, etc. This article describes the status of CRL's mobile satellite communication experiments using ETS-V. Author

#### A90-25734#

##### **APPLICATION OF A DIGITAL CONTROL THEORY FOR GENERATING ADAPTIVE GRIDS**

HIROSHI MATSUMURA (Kawasaki Heavy Industries, Ltd., Kakamigahara, Japan) and MAKOTO KOBAYAKAWA (Kyoto University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 116-121. refs

A new method of adaptive grid generation is presented. In this method, digital control theory is applied to the generation of the computational grid. The purpose of adaptive grid is to diminish truncation error and to increase the smoothness and orthogonality of grid lines. The performance index of the linear optimal regulator has a strong relation to the characteristics of the adaptive grids. The digital linear optimal regulator is then used for the adaptive grid generation. The numerical example of a NACA-0012 airfoil flow field shows strong clustering of grid lines at shock wave. Author

Author

#### A90-25764#

##### **TOPOLOGY OF COMPUTED INCOMPRESSIBLE THREE-DIMENSIONAL SEPARATED FLOW FIELD AROUND HIGH-ANGLE-OF-ATTACK CONE-CYLINDERS**

KOJIRO SUZUKI and HIROTOSHI KUBOTA (Tokyo, University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 317-322. refs

The topological properties of three-dimensional separation are discussed in view of their general representation as a composition of finite types of basic elements correlated with such corresponding flow-phenomena as the vortex-core line. Attention is given to the illustrative numerical case of a separated flow field around a high-angle-of-attack cone-cylinder. The topological characteristics obtained indicate that the calculation is reasonably accurate with respect to such features of experimental results as the asymmetric arrangement of the leeside vortices. O.C.

#### A90-25770#

##### **PROBLEM AREAS IN APPLIED COMPUTATIONAL FLUID DYNAMICS**

HIDEO YOSHIHARA (Office of Naval Research, Tokyo, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 353-358.

The present consideration of Navier-Stokes solutions in applied CFD studies gives attention to the problems posed by: (1) turbulence modeling for strong, transonic shock/boundary-layer interactions; (2) large computational costs; and (3) the capture of highly-swept shocks and vortex layers. Slow convergence is addressed through a removal of the stiffness in the Navier-Stokes equations, which dominates the rate of surface wave generation by restricting the time-step in the vicinity of the surface. A straightforward way of accelerating convergence is the overrelaxation of the correction at selected control mesh points. O.C.



**A90-25801#****COMPUTATION OF 2D NAVIER-STOKES EQUATIONS**

SUNIL KUMAR CHAKRABARTTY (National Aeronautical Laboratory, Bangalore, India) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 578-583. refs

Two schemes for computing two-dimensional Navier-Stokes equations are described and applied to laminar flow over a flat plate and viscous flow over a NACA0012 airfoil. The variation of local skin-friction coefficient with local Reynolds number is compared with the Blasius solution and that of Swanson and Turkel (1985). The effect of free-stream Mach number on the temperature profile is shown, and a comparison is made of velocity profile at  $M(\infty) = 0.50$  and  $Re = 500$ , with no artificial viscosity used for stability. Pressure distributions, local skin friction distributions, and velocity profiles on the airfoil and wake are presented. C.D.

**A90-25811#****AN AUTOMATIC EULER SOLVER USING UNSTRUCTURED UPWIND METHOD**

KAZUHIRO NAKAHASHI and KOUICHI EGAMI (Osaka Prefecture University, Sakai, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 647-652. refs

An unstructured generation method and an unstructured upwind method for improving the computational procedure in CFD are described. The unstructured grid is generated using adaptive refinement techniques. The geometry-adaptive refinement stage and solution-adaptive refinement stages for grid generation are examined. The development of an automatic flow solver involves the use of the flux-vector splitting of Van Leer (1986), the MUSCL approach, and time integration. The automatic flow solver is applied to multielement airfoil and to internal flow computation. It is noted that the automatic flow solver is useful for internal and external flow field, single and multiple bodies, and low subsonic to hypersonic flow conditions. Diagrams of grids are provided. I.F.

**A90-25861#****APPLICATION OF LOMAX-BAILEY IMPLICIT SCHEME TO REACTIVE FLOWS**

HIROSHI FUJII, MICHIO NAKANO, MASATO TAMURA, and NORIHIKO YOSHIKAWA (Toyoashi University of Technology, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1019-1024. refs

A single-step, linearized implicit scheme developed by Lomax and Bailey (1967) is used here to solve stiff chemical kinetics equations relevant to the numerical prediction of supersonic combustion propulsion. The method is applied here to analyze constant volume combustion, one-dimensional Chapman-Jouguet detonation structure, and ignition phenomena behind reflected shock waves. C.D.

**A90-25873#****SUPERSONIC VISCOUS SHEAR LAYERS**

YOSHIKI TAKAHASHI and TOSHI FUJIWARA (Nagoya University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1138-1143.

The supersonic shear flow patterns associated with fuel-air mixing in supersonic combustion are studied here by numerical analysis of two-dimensional supersonic viscous shear flows. An attempt is made to clarify the difference between subsonic and supersonic flows. Backward shear layers are observed to interact strongly with each other, while supersonic shear layers under strong constriction cause the entire flow field to oscillate with large-scale instabilities. The mixing behavior depends on the aspect ratio. The shape and number of vortices generated on the shear surface

depends on whether the turbulent model used is based on the LES model or the k-epsilon model. Forward shear layers provide virtually no mixing compared with backward ones. Forward shear flow converges to a stationary state. C.D.

**A90-25885#****TOPOLOGICAL STUDY OF THREE-DIMENSIONAL VORTEX INTERACTIONS**

K. OSHIMA, Y. OSHIMA, and N. IZUTSU (Institute of Space and Astronautical Science, Sagami-hara, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1234-1239. refs

The flows around a two-dimensional unsteady airfoil have been successfully simulated by a discrete vortex method in which the shedded vortices are determined using the global Kutta condition. The simulation is based on experimental observations and can be used to determine the strength of bound circulation during numerical simulation of airfoil flows with large separation regions. The shedded vortex street tends to be locked to a Strouhal number which corresponds to the one for a steady obstacle with the same blockage area. During this process, pairing or splitting of the vortex street is observed. Cutting and reconnection of vortex filaments was observed in the three-dimensional viscous flow for vortex rings proceeding side by side along the parallel axes in the experiments as well as in the numerical simulation using the Navier-Stokes equations. The Rosenhead-Moore approximation in the three-dimensional discrete vortex method can simulate these processes. C.D.

**A90-26059****FRONTIERS IN EXPERIMENTAL FLUID MECHANICS**

MOHAMED GAD-EL-HAK, ED. (Notre Dame, University, IN) Berlin and New York, Springer-Verlag (Lecture Notes in Engineering. Volume 46), 1989, 538 p. For individual items see A90-26060 to A90-26068.

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The papers presented in this volume provide an overview of recent research in fluid mechanics, each paper emphasizing the use of experiments to achieve a better physical understanding of a particular class of flow problems. Topics discussed include the influence of developments in dynamical systems theory on experimental fluid mechanics; low speed, indraft wind tunnels; high-Reynolds number liquid flow measurements; and the turbulent boundary layer. Papers are also presented on unsteady pulsing in cylinder wakes, vortex dynamics of delta wings, and the aeroacoustics of trailing edges. V.L.

**A90-26077****UNIFIED OPTIMAL CRITERION METHOD - COMBINATION OF DIRECTION OF GRADIENT AND EJECTION LINE**

Y.-S. FENG (Northwestern Polytechnical University, Xian, People's Republic of China) Computers and Structures (ISSN 0045-7949), vol. 34, no. 4, 1990, p. 629-632.

Copyright

The iterative optimization algorithm developed by Feng (1984) for weight minimization of large-scale structures is extended and refined. Formulations are derived for general optimization problems with single constraints and for a broad class of problems with multiple constraints (e.g., stress, displacement, vibration, service life, and reliability). It is suggested that the simplicity and clarity of the physical concepts underlying the present approach make it readily applicable to practical problems in aircraft design. T.K.

**A90-26751****DEVELOPMENT OF FATIGUE LOADING SPECTRA**

JOHN M. POTTER, ED. (USAF, Wright-Patterson AFB, OH) and ROY T. WATANABE, ED. (Boeing Commercial Airplanes, Seattle, WA) Philadelphia, PA, American Society for Testing and Materials, 1989, 243 p. For individual items see A90-26752 to A90-26759. (ASTM STP-1006) Copyright

The present work on fatigue-loading spectra encompasses the

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current status of standardized stress-time histories, European approaches to standard loading spectrum development, transport aircraft airframe fatigue test spectra, the 'TURBISTAN' fatigue-loading standard for fighter-aircraft engine disks, an automated procedure for the creation of flight-by-flight spectra, and the development of a wave-action standard history for fatigue testing relevant to tubular structures in the North Sea. Also treated is the use of the TURBISTAN mission spectra to evaluate fatigue crack growth in a rotating disk, fatigue-spectra development for airborne stores, a simplified analysis of fatigue-loading spectra, variable-amplitude load models for fatigue-damage crack growth, the tracking time service histories for multiaxis fatigue problems, and the compilation of procedures for fatigue crack propagation testing under complex load sequences. O.C.

### A90-26752

#### STANDARDIZED STRESS-TIME HISTORIES - AN OVERVIEW

WALTER SCHUETZ (Industrieanlagen-Betriebsgesellschaft mbH, Ottobrunn, Federal Republic of Germany) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 3-16. refs  
Copyright

A standardized stress-time history (SSTH) must have its basis in as many service-conducted stress measurements as possible, and its character must be that of a fixed stress sequence, rather than merely a spectrum for which an infinite number of stress-time histories are possible. Truncation or omission levels, if any, must be both clearly stated and substantiated by tests. SSTHs should be used for the comparison of materials, production processes, and design details, as well as cooperative test programs; they are also applicable to fatigue-life scatter investigations, and the production of preliminary fatigue design data for components when the service loads on said component are of variable amplitude. O.C.

### A90-26754

#### BASIC APPROACH IN THE DEVELOPMENT OF TURBISTAN, A LOADING STANDARD FOR FIGHTER AIRCRAFT ENGINE DISKS

GUENTER E. BREITKOPF (Motoren- und Turbinen-Union Muenchen GmbH, Munich, Federal Republic of Germany) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 65-78.  
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The TURBISTAN loading standard for high performance aircraft gas turbine disks typically involves a load sequence of 100 flights, equalling 7726 cycles, for a total test duration of 22.2 min in the performance of a sequence. This load sequence represents a unique standard for LCF and crack growth experiments, maximally reflecting typical engine rotor conditions at low temperatures, where creep phenomena are of secondary importance. Attention is given to illustrative TURBISTAN data obtained for air combat, transition/training, ground attack, and navigation mission types. O.C.

### A90-26759

#### COMPILATION OF PROCEDURES FOR FATIGUE CRACK PROPAGATION TESTING UNDER COMPLEX LOAD SEQUENCES

R. SUNDER (USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 211-230. refs  
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A review is made of procedures, developed at the National Aeronautical Laboratory for fatigue crack propagation testing under flight spectrum loading. They include K-control and on-line spectrum editing that were found to have a significant impact on spectrum load testing. Techniques are described for unambiguous assessment of crack closure stress and for binary-coded marker loading. Author

### A90-26893#

#### A STUDY ON SPRAY CHARACTERISTICS DOWN STREAM FROM A GUTTER-ATOMIZER

ZHIGANG LIU and JIAHUA WANG (Nanjing Institute of Aeronautics, People's Republic of China) Journal of Propulsion Technology (ISSN 1001-4055), Feb. 1990, p. 38-43, 82. In Chinese, with abstract in English. refs

Based on the study on spray characteristics at the exit of a gutter-atomizer, the spray concentration distribution downstream from the gutter-atomizer is measured by means of laser holography. In this paper the variation of atomization performance in the spray is studied, and the effects of the width of gutter, the diameter of atomizer, and the air speed on the atomization performance is also discussed. Author

### A90-26978\*#

#### Aerometrics, Inc., Sunnyvale, CA. DEVELOPMENT OF A PHASE DOPPLER BASED PROBE FOR ICING CLOUD DROPLET CHARACTERIZATION

R. C. RUDOFF, J. N. SMITH, and W. D. BACHALO (Aerometrics, Inc., Sunnyvale Technology Center, CA) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 13 p. refs (Contract NAS3-25653)  
(AIAA PAPER 90-0667) Copyright

The development and evaluation of a compact optical fiber probe (OFP) for airborne and wind tunnel icing cloud characterizations is described. This probe was based upon the proven phase Doppler technique for measuring the size and velocity of spherical drops. Direct comparisons of the size distributions from the standard PDPA with the OFP were used to confirm the reliability of the probe. After some improvements in the fiber coupling efficiency, the number density and liquid water content data agreed to within 15 percent. Author

### A90-27425

#### THE SELECTION OF ACTUATION DEVICES FOR AIRCRAFT PNEUMATIC VALVES IN SYSTEMS UNDER COMPUTER CONTROL

MICHAEL A. MCCOLLUM (Allied-Signal Aerospace Co., Garrett Fluid Systems Div., Tempe, AZ) SAE, Intersociety Conference on Environmental Systems, 19th, San Diego, CA, July 24-26, 1989. 16 p.  
(SAE PAPER 891456) Copyright

Performance requirements are presented for valves in four different aircraft pneumatic systems, giving attention to the power input called for by each. A method is devised for calculating the actuation power needed to ensure proper valve actuation, and the relative merits of the four actuation methods, namely electrohydraulic, electropneumatic, servomotor-electromechanical, and stepper-motor electromechanical, are discussed in view of overall system weight. A graph is presented which characterizes system weights for existing aircraft valve requirements. O.C.

### N90-16958#

#### European Space Agency, Paris (France). COMBUSTION EXPERIMENTS DURING KC-135 PARABOLIC FLIGHTS

BRIGITTE KALDEICH, ed. Aug. 1989 71 p Original contains color illustrations  
(ESA-SP-1113; ISBN-92-9092-008-4; ETN-90-96197) Copyright  
Avail: NTIS HC A04/MF A01; ESA Publications Div., ESTEC, Noordwijk, Netherlands, 30 Dutch guilders

The results of combustion experiments conducted during the parabolic flights of KC-135 aircraft in 1986 and 1987 are presented. The aim of the project is the investigation of combustion phenomena under microgravity conditions. The areas of interest are the following: solid surface combustion, flame spreading, liquid surface combustion (pool fires), droplet combustion and evaporation, particle cloud combustion, premixed gas flame propagation, gas jet diffusion flames, turbulent flow combustion control of flames by electric fields and fire safety aspects. The results obtained clearly demonstrate the value of parabolic flights for short-duration experiments. Even though residual accelerations and g-jitter are considerable, quantitative results are obtained and

valuable experience is gained with these experiments.

ESA

**N90-16969#** National Science Foundation, Washington, DC. Div. of Science Resources Studies, Surveys, and Analysis Section.

**PROFILES-AERONAUTICAL/ASTRONAUTICAL ENGINEERING: HUMAN RESOURCES AND FUNDING Special Report, 1976 - 1986**

MARY V. BURKE Nov. 1988 157 p  
(PB90-103888; NSF-89-314) Avail: NTIS HC A08/MF A01  
CSCL 13/2

Attention is focused on the field of aeronautical/astronautical engineering. This report provides current and historical information on personnel, education, and funding for the field through the use of graphs and detailed statistical tables. GRA

**N90-16971#** Center for Night Vision and Electro-Optics, Fort Belvoir, VA.

**REDUCED VOLTAGE AND RESTART TESTING OF THE 1-WATT INTEGRAL CRYOGENIC COOLER (HD-1033B/C/D) Final Report, 4 Apr. - 12 May 1988**

H. DUNMIRE and J. SHAFFER Sep. 1989 94 p  
(AD-A215133; AMSEL-NV-TR-0085) Avail: NTIS HC A05/MF A01 CSCL 20/13

This final report describes and provides the data on the reduced voltage (108 VAC) and restart testing of the 1-Watt Integral Stirling Cooler. The 1-Watt Integral Cooler (HD-1033B/C/D) is currently used in the M1 FLIR, M60 FLIR, and the Advanced Attack Helicopter FLIR. The cooler specification requires that the cooler operate from 115 to 119 VAC. Because of the potential of lower voltage operation in some systems, C2NVEO evaluated the cooler performance and restartability at environmental extremes with 108 VAC. The coolers successfully passed all testing at all environmental conditions using both voltages. GRA

**N90-17045** Stanford Univ., CA.

**AN EXPERIMENTAL STUDY OF THE EFFECT OF STREAMWISE VORTICES ON UNSTEADY TURBULENT BOUNDARY-LAYER SEPARATION Ph.D. Thesis**

WILLIAM WARREN HUMPHREYS 1989 271 p  
Avail: Univ. Microfilms Order No. DA8919434

This experiment studied the effect of embedded streamwise vortices on unsteady turbulent boundary-layer separation. The objectives were to document the flow field, to characterize the time response of the boundary layer, and to understand the actual mechanisms by which the streamwise vortices modify boundary-layer behavior. A new configuration for non-obtrusive three-component Laser Doppler Anemometry (LDA) determined the phase averaged velocity and Reynolds stress components, in an unsteady water tunnel, at a momentum thickness Reynolds number of 1840. The stream-wise vortices were created by three pairs of half-delta wing vortex generators, while the boundary-layer separation was controlled through impulsively initiated opposite-wall suction, which created a strong adverse pressure gradient. The time response of the freestream velocity demonstrates that convection is the primary mechanism by which vortex generators modify the response of the boundary layer. Modeling the response with two time scales proved to be a useful technique. There is an initial fast response throughout the boundary layer which is unaffected by the presence of vortex generators, followed by a slow or convective response, the magnitude of which is substantially modified by the presence of the vortex generators.

Dissert. Abstr.

**N90-17055\*#** McDonnell Aircraft Co., Saint Louis, MO.

**HEAT PIPES FOR WING LEADING EDGES OF HYPERSONIC VEHICLES Final Report**

B. L. BOMAN, K. M. CITRIN, E. C. GARNER, and J. E. STONE  
Jan. 1990 122 p  
(Contract NAS1-18144)  
(NASA-CR-181922; NAS 1.26:181922) Avail: NTIS HC A06/MF A01 CSCL 20/4

Wing leading edge heat pipes were conceptually designed for

three types of vehicle: an entry research vehicle, aero-space plane, and advanced shuttle. A full scale, internally instrumented sodium/Hastelloy X heat pipe was successfully designed and fabricated for the advanced shuttle application. The 69.4 inch long heat pipe reduces peak leading edge temperatures from 3500 F to 1800 F. It is internally instrumented with thermocouples and pressure transducers to measure sodium vapor qualities. Large thermal gradients and consequently large thermal stresses, which have the potential of limiting heat pipe life, were predicted to occur during startup. A test stand and test plan were developed for subsequent testing of this heat pipe. Heat pipe manufacturing technology was advanced during this program, including the development of an innovative technique for wick installation.

Author

**N90-17074\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**OPTIMUM ELEMENT DENSITY STUDIES FOR FINITE-ELEMENT THERMAL ANALYSIS OF HYPERSONIC AIRCRAFT STRUCTURES**

WILLIAM L. KO, TIMOTHY OLONA, and KYLE M. MURAMOTO  
Jan. 1990 36 p  
(NASA-TM-4163; H-1519; NAS 1.15:4163) Avail: NTIS HC A03/MF A01 CSCL 20/4

Different finite element models previously set up for thermal analysis of the space shuttle orbiter structure are discussed and their shortcomings identified. Element density criteria are established for the finite element thermal modelings of space shuttle orbiter-type large, hypersonic aircraft structures. These criteria are based on rigorous studies on solution accuracies using different finite element models having different element densities set up for one cell of the orbiter wing. Also, a method for optimization of the transient thermal analysis computer central processing unit (CPU) time is discussed. Based on the newly established element density criteria, the orbiter wing midspan segment was modeled for the examination of thermal analysis solution accuracies and the extent of computation CPU time requirements. The results showed that the distributions of the structural temperatures and the thermal stresses obtained from this wing segment model were satisfactory and the computation CPU time was at the acceptable level. The studies offered the hope that modeling the large, hypersonic aircraft structures using high-density elements for transient thermal analysis is possible if a CPU optimization technique was used. Author

**N90-17084** California Univ., Los Angeles.

**FORMULATION AND VERIFICATION OF A TECHNIQUE FOR COMPENSATION OF PNEUMATIC ATTENUATION ERRORS IN AIRBORNE PRESSURE SENSING DEVICES Ph.D. Thesis**

STEPHEN ANTHONY WHITMORE 1989 203 p  
Avail: Univ. Microfilms Order No. DA8922215

Recent advances in aircraft performance and maneuver capability have dramatically complicated the problem of flight control augmentation. With increasing regularity, aircraft system designs require that aerodynamic parameters derived from pneumatic measurements be used as control system feedbacks. These requirements necessitate that pneumatic data be measured with accuracy and fidelity. The emphasis here is on the development of a general numerical model for accurately predicting pneumatic attenuation errors in pressure sensing devices. Once the model was developed and verified, then techniques for inverting the model to provide a compensation algorithm were developed. A mathematical model, derived from the Navier-Stokes equations is used to predict the behavior of pneumatic configurations which are subjected to small but arbitrary inputs. Comparisons of the mathematical model to both lab and flight data indicate that its predictive capability is excellent. Two approaches for inverting the model to provide a compensation algorithm were developed. The first approach relied on the techniques of statistical deconvolution to develop a compensation model. The second technique overcame the difficulty of limited applicability inherent in the first approach by incorporating the dynamic model into the compensation routine

using the techniques of Minimum Variance Estimation Theory. The latter algorithm has a broader range of applicability.

Dissert. Abstr.

**N90-17112\*#** Eloret Corp., Sunnyvale, CA.  
**SHOCK LAYER VACUUM UV SPECTROSCOPY IN AN ARC-JET WIND TUNNEL**

G. PALUMBO Jan. 1990 17 p Presented at the 35th International Instrumentation Symposium, Orlando, FL, 30 Apr. - 4 May 1988

(NASA-TM-102258; A-90017; NAS 1.15:102258) Avail: NTIS HC A03/MF A01 CSCL 14/2

An experimental program is being developed to obtain measurements of the incident surface radiation in the 1000 Å to 2000 Å range from the shock stagnation region of a blunt model in the Ames 20 MW Arc-Jet Wind Tunnel. The setup consists of a water-cooled blunt model, with a magnesium fluoride forward-viewing window. Radiation incident on the window is optically imaged via an evacuated system and reflective optical elements onto the entrance slit of a spectrograph. The model will be exposed to the supersonic plasma stream from the exit nozzle of the arc-jet tunnel. The resulting bow shock radiation will be measured. It is expected that this experiment will help evaluate the importance of atomic N and O lines to the radiative heating of future Aeroassist Space Transfer Vehicles (ASTVs). Author

**N90-17113#** Institut Franco-Allemand de Recherches, Saint-Louis (France).

**SELF COMPENSATION OF RIGID DISPLACEMENTS IN HOLOGRAPHIC INTERFEROMETRY [AUTOCOMPENSATION DES DEPLACEMENTS RIGIDES EN INTERFEROMETRIE HOLOGRAPHIQUE]**

A. STIMPFLING 30 Jun. 1988 10 p In FRENCH Presented at the OPTO 88 Conference, Paris, France, 17-18 May 1988 (ISL-CO-219/88; ETN-90-96086) Avail: NTIS HC A02/MF A01

A method called integral holographic initialization is used to compensate perfectly the displacements of the whole object, and to compensate for local deformation. It allows the recording of interferograms obtained by time integration of a moving vibrating target. The experiments carried out with a continuous laser show that the method compensates completely and automatically any displacement of any amplitude of the target object. The application to study defects in aircraft structures is discussed. ESA

**N90-17193** ESDU International Ltd., London (England).  
**FATIGUE OF ALUMINIUM ALLOY JOINTS WITH VARIOUS FASTENER SYSTEMS. LOW LOAD TRANSFER Abstract Only**  
 Nov. 1989 35 p  
 (ESDU-89046; ISBN-0-85679-720-0; ISSN-0958-0379) Avail: ESDU

ESDU 89046 presents the results of over 900 axial load fatigue tests extracted from the literature on low load transfer joints under constant or variable amplitude loading. A low load transfer joint is one in which less than 10 percent of the axial load is transferred between the members and typically over half the joints in an airframe fall in this category, for example a skin-stiffener connection in a wing. Five different types of fastener are included, assembled with a range of fits from clearance to interference and with a variety of interlays. The data allows a choice to be made of the most appropriate system to improve fatigue strength under a given loading. Details of the alloys (7010-T7651, 2014-T651, 2024-T351, 2024-T3 clad or unclad, 7050-T76 or T7651 and 7475-T351) and of the test specimens are included and the influence of the various parameters on fatigue strength is discussed. Included are data for joints manufactured with a corner crack in the fastener hole; these tests were designed to investigate a repair in which the hole is drilled out but insufficiently to eliminate an existing crack. ESDU

**N90-17930#** Federal Aviation Administration, Atlantic City, NJ. Technical Center.  
**PRELIMINARY FIRE EXTINGUISHING TESTS WITH HANDHELD BOTTLES: A COMPARISON OF EXTINGUISHING**

**COMPOUNDS**

T. M. GUASTAVINO and F. FANN Jan. 1990 30 p  
 (DOT/FAA/CT-TN89/60) Avail: NTIS HC A03/MF A01

In 1982, the Federal Aviation Administration (FAA) Technical Center completed a test and evaluation project on use of handheld extinguishers in transport category aircraft. Some of the tests involved the comparative effectiveness of handheld extinguishers in a specific fire scenario: a triple non-fireblocked aircraft seat ignited with gasoline. The test work included the identification and quantification of effluent gas species produced by the fire and the extinguishing chemicals. The comparative effectiveness of the extinguishers used in the above tests and some newer systems in two distinct fire tests are described. The first test is the crib test used by Underwriters Laboratory, Inc. to rate handheld extinguishers. The second test is the same seat test used in the earlier work. The tests employed aircraft approved water extinguishers and Halon 1211 extinguishers as benchmarks. New formulations using surfactants and extinguishing powders in aqueous solutions were tested against the benchmark performance levels. In these tests, certain new solutions were able to meet or exceed the performance of the benchmark agents. Author

**N90-17936#** Concordia Univ., Montreal (Quebec). EMC Lab.  
**MEASUREMENT AND COMPUTER SIMULATION OF ANTENNAS ON SHIPS AND AIRCRAFT FOR RESULTS OF OPERATIONAL RELIABILITY**

STANLEY J. KUBINA In AGARD, Modern Antenna Design Using Computers and Measurement: Application to Antenna Problems of Military Interest 28 p Sep. 1989 Sponsored in part by Defence Research Establishment, Ottawa, and by National Sciences and Engineering Research Council  
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The review of the status of computational electromagnetics by Miller and the exposition by Burke of the developments in one of the more important computer codes in the application of the electric field integral equation method, the Numerical Electromagnetic Code (NEC), coupled with Molinet's summary of progress in techniques based on the Geometrical Theory of Diffraction (GTD), provide a clear perspective on the maturity of the modern discipline of computational electromagnetics and its potential. Audone's exposition of the application to the computation of Radar Scattering Cross-section (RCS) is an indication of the breadth of practical applications and his exploitation of modern near-field measurement techniques reminds one of progress in the measurement discipline which is essential to the validation or calibration of computational modeling methodology when applied to complex structures such as aircraft and ships. The latter monograph also presents some comparison results with computational models. Some of the results presented for scale model and flight measurements show some serious disagreements in the lobe structure which would require some detailed examination. This also applies to the radiation patterns obtained by flight measurement compared with those obtained using wire-grid models and integral equation modeling methods. In the examples which follow, an attempt is made to match measurements results completely over the entire 2 to 30 MHz HF range for antennas on a large patrol aircraft. The problem of validating computer models of HF antennas on a helicopter and using computer models to generate radiation pattern information which cannot be obtained by measurements are discussed. The use of NEC computer models to analyze top-side ship configurations where measurement results are not available and only self-validation measures are available or at best comparisons with an alternate GTD computer modeling technique is also discussed. Author

**N90-17939#** Societe Mothesim, Le Plessis-Robinson (France).  
**GTD/UTD: BRIEF HISTORY OF SUCCESSIVE DEVELOPMENT OF THEORY AND RECENT ADVANCES. APPLICATIONS TO ANTENNAS ON SHIPS AND AIRCRAFT**  
 F. A. MOLINET In AGARD, Modern Antenna Design Using Computers and Measurement: Application to Antenna Problems

of Military Interest 22 p Sep. 1989

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The basic concepts of Geometrical Theory of Diffraction (GTD) and its relation to the wave equation are reviewed in the frame-work of asymptotic expansions which historically formed the basis for further developments and improvements of the theory. Uniform solutions and especially the Uniform Theory of Diffraction (UTD) are introduced and a brief synthesis of successive development of GTD/UTD is presented. Among the subjects which were recently advanced, those which either lead to fundamental improvements of the theory or which have an important impact on its applications to current radiation and scattering problems have been selected and analyzed in more details. A great emphasis is given to the extension of GTD/UTD to metallic bodies with coatings. Finally some general ideas for conceiving a computer program founded on GTD/UTD are presented together with some software packages which were recently developed in France. A few selected applications of these computer programs to predict the EM radiation from antennas on an aircraft or a spacecraft and on a ship are described and illustrated by graphical displays. Author

**N90-17941#** British Aerospace Dynamics Group, Bristol (England). Microwave Antennas.

**ANTENNA INSTALLATION ON AIRCRAFT: THEORY AND PRACTICE**

T. J. MURPHY /in AGARD, Modern Antenna Design Using Computers and Measurement: Application to Antenna Problems of Military Interest 8 p Sep. 1989

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The problems to be faced in the integration of an antenna system onto an aircraft are reviewed. The techniques, both mathematical and empirical, used to assess radiation pattern performance are placed in the context of the requirement on the airframe as a system. A systematic approach to the integration task is described which experience has shown to be suited to the overall task. Author

**N90-17970#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**AUTOMATION OF AN RCS (RADAR CROSS SECTION) MEASUREMENT SYSTEM AND ITS APPLICATION TO INVESTIGATE THE ELECTROMAGNETIC SCATTERING FROM SCALE MODEL AIRCRAFT CANOPIES M.S. Thesis**

SCOTT A. OWENS Dec. 1989 157 p (AD-A215741; AFIT/GE/ENG/89D-38) Avail: NTIS HC A08/MF A01 CSCL 20/14

The purpose of this study was twofold, the first objective was to complete the development of AFIT's Far-Field Radar Range with a fully automated measurement process. The second objective was to use the facility to investigate the scattering of metallic versus transparent aircraft canopies relative to the scattering of the total aircraft. The approach for the investigation was: (1) to measure scale model aircraft to determine the effect of the RCS of the canopy/cockpit area on the RCS of the total aircraft; and (2) to design and measure a test body which would isolate the canopy/cockpit area from the rest of the aircraft. The result of the work on the first task is a software package called AFIT RCS Measurement Software (ARMS). The successful performance of the far-field range was validated by very favorable comparisons with the Wright Research and Development Center's anechoic chamber. The scale model measurements suggest at most a 5 dB difference between the scattering from the two extreme cases. The test body, however, clearly demonstrated differences up to 20 dB at certain frequencies. This study documents the upper and lower bounds of the subject measurements in an indoor measurement range. The Air Force has expressed interest in steering the investigation to examine materials and/or canopy construction. GRA

**N90-17984#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**TRACKING A HYPERSONIC AIRCRAFT FROM A SPACE PLATFORM M.S. Thesis**

DAVID W. ZIEGLER Dec. 1989 117 p (AD-A216399; AFIT/GA/ENY/89D-7) Avail: NTIS HC A06/MF A01 CSCL 17/11

This study developed a data processing algorithm for a space-based platform engaged in tracking a hypersonic transatmospheric vehicle. The geosynchronous platform was assumed to possess passive sensors measuring target position from data angles. The hypersonic vehicle was assumed to be operating in the outer fringes of the atmosphere. Four element and six element state Kalman filters were developed, coded, and tested against typical transatmospheric flight profiles. Accuracy of the filters in estimating position, velocity, heading, and acceleration was determined for 1, 5, and 10 second data intervals. From this test data, it was concluded that the six element state Kalman filter posed a viable option for tracking and estimating performance of hypersonic aircraft. GRA

**N90-18016#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**MODELING THE WAKE AS A CONTINUOUS VORTEX SHEET IN A POTENTIAL-FLOW SOLUTION USING VORTEX PANELS M.S. Thesis**

ROBERT J. PAPKA Dec. 1989 96 p (AD-A216220; AFIT/GAE/ENY/89D-26) Avail: NTIS HC A05/MF A01 CSCL 20/4

An investigation was made to determine the advantages of modeling the wake as a continuous vortex sheet in an unsteady potential-flow computer model. The existing program modeled the body as a continuous vortex sheet, and modeled the wake as discrete vortex cores employing principles of vortex lattice methods. A method is developed to approximate the wake with triangular vortex panels. The method accounts for redistributing vortex strength as the panels expand and deform. Comparisons are made with results of the original program for a rectangular wing at varying angles of attack. Limited results suggest the method is valid, and areas for further study are recommended. GRA

**N90-18017#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**NUMERICAL SIMULATION OF COMPRESSIBLE VORTICES M.S. Thesis**

SCOTT ANDREW MORTON Dec. 1989 61 p (AD-A216221; AFIT/GAE/ENY/89D-24) Avail: NTIS HC A04/MF A01 CSCL 20/4

A delta wing at a high angle of attack produces two vortices that generally undergo dramatic increases in core size, followed by the formation of regions of reversed flow. This phenomenon is called vortex breakdown and can have significant effects on the aircraft's lift, drag, and moment coefficients. The objective of this thesis is to provide a base line model of the compressible vortex, independent of the complex body interaction with the delta wing. The mathematical model is then used to simulate vortex breakdown for various vortex strengths, Reynolds numbers, and Mach numbers with particular attention given to the effects of compressibility. After running many simulations it was found that Mach number has a favorable effect by delaying vortex breakdown as defined above. Holding Reynolds number and vortex strength constant while increasing Mach number reduced the effective vortex strength while compressing the flow. Another important result of this compressible flow study was the disappearance of non-unique solutions at  $Re = 200$  and  $V = 1.0$  as Mach number was increased. No paths of non-unique solutions were found for  $M$  greater than 0.2. GRA

**N90-18020#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**FLUCTUATING WIND FORCES MEASURED ON A BLUFF BODY EXTENDING FROM A CAVITY M.S. Thesis**

## 12 ENGINEERING

BRIAN W. KING Dec. 1989 198 p  
(AD-A216414; AFIT/GAE/ENY/89D-19) Avail: NTIS HC  
A09/MF A01 CSCL 20/4

The effect of wind forces measured on a bluff body extending from a cavity was investigated. This was accomplished by measuring wind induced vibratory inputs to a plexiglas bluff body model. The model extended from a ground board cavity installed in the AFIT 5-Foot Wind Tunnel. Forces and moments were measured from an 8 element load cell unit built and installed in the base of a plexiglas model. Three different size cavity openings were tested for both a no-rotation and 45 degree rotation referenced to the wind. Data was taken at individual speed points between 55 ft/s and 180 ft/s, producing Reynolds number based on model width in the range of  $1.5 \times 10$  to the 5th power to  $5.0 \times 10$  to the 5th power. Baseline data for a closed cavity configuration was collected and compared to previous studies conducted at the USAF Academy. Force and moment coefficient data are presented, comparing cavity opening and model rotation effects. Results of shedding frequency analysis are presented based on transient data recorded. GRA

**N90-18030#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

### **ANALYSIS AND TEST OF A WIDE ANGLE SPECTROMETER M.S. Thesis**

ROBERT D. KAISER Dec. 1989 94 p  
(AD-A215819; AFIT/GEP/ENP/89D-6) Avail: NTIS HC A05/MF  
A01 CSCL 15/3

An analysis and test of a design for a laser warning receiver which provides aircrew warning and collects threat data is described. The analysis and test includes the optics and detector of the system. A design for a device to measure wavelength, angle of arrival, and energy of a laser pulse is analyzed and tested. The instrument has a 180 degree field of view and an operating range of 400 nm to 800 nm. In a series of tests the instrument was found to measure angle of arrival accurately to within  $\pm 41$  arc minutes and a wavelength to within 1 nm. A variation of  $\pm 20$  percent in the measurement of pulse energy per unit area was found for small changes in angle of arrival. The system was thermal noise limited and could detect a pulse that was  $1/45$  of the Maximum Permissible Exposure (MPE) with an uncooled detector. When using a detector cooled to  $-10$  C, the system could detect a pulse  $1/22000$  of the MPE. This research is an attempt to design, analyze, prototype, and test an approach to meeting this need which uses a cylindrical lens and a spectrometer equipped with an area detector. GRA

**N90-18038#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

### **EXPERIMENTAL INVESTIGATION OF A CHEMICAL LASER CAVITY FLOWFIELD M.S. Thesis**

STEPHEN WALTER STIGLICH, JR. Dec. 1989 122 p  
(AD-A216398; AFIT/GAE/ENY/89D-36) Avail: NTIS HC  
A06/MF A01 CSCL 09/3

Chemical lasers require a cavity that establishes and maintains the proper gas dynamic properties during lasing. The design and performance of a flow system capable of supporting the hypersonic flow conditions in a lasing cavity are described. Using cold air as the working medium, the flow control system configuration and nozzle-cavity-supersonic diffuser assembly configuration were developed to establish acceptable flow conditions in the test section. Performance evaluation was based on pressure measurements in the nozzle-cavity-diffuser assembly and schlieren photographs of the flowfield in the cavity. Flow conditions in the test section were broken up into three different regions: flow in the hypersonic nozzles, flow in the base region and flow in the cavity region. Flow in the nozzles was analyzed using one-dimensional, steady, isentropic flow theory. Test results indicated that the hypersonic nozzles performed to design specifications. The Korst two-dimensional base-pressure flow model was used to describe the flow in the nozzle exit plane and base region. Experimentally calculated Mach numbers and static

pressures corresponded very closely to theoretical values. Static pressure ports and schlieren photographs were used to describe the flow-field conditions in the cavity region. GRA

**N90-18041\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

### **GEAR NOISE, VIBRATION, AND DIAGNOSTIC STUDIES AT NASA LEWIS RESEARCH CENTER**

JAMES J. ZAKRAJSEK, FRED B. OSWALD, DENNIS P. TOWNSEND, and JOHN J. COY 1990 10 p Prepared for presentation at the 1st International Conference on Gear Box Noise and Vibration, Cambridge, England, 10-11 Apr. 1990; sponsored by the Institution of Mechanical Engineers (Contract DA PROJ. 1L1-62209-A4-7A) (NASA-TM-102435; E-5204; NAS 1.15:102435; AVSCOM-TR-89-C-020) Avail: NTIS HC A02/MF A01 CSCL 13/9

The NASA Lewis Research Center and the U.S. Army Aviation Systems Command are involved in a joint research program to advance the technology of rotorcraft transmissions. This program consists of analytical as well as experimental efforts to achieve the overall goals of reducing weight, noise, and vibration, while increasing life and reliability. Recent analytical activities are highlighted in the areas of gear noise, vibration, and diagnostics performed in-house and through NASA and U.S. Army sponsored grants and contracts. These activities include studies of gear tooth profiles to reduce transmission error and vibration as well as gear housing and rotordynamic modeling to reduce structural vibration transmission and noise radiation, and basic research into current gear failure diagnostic methodologies. Results of these activities are presented along with an overview of near term research plans in the gear noise, vibration, and diagnostics area. Author

**N90-18057\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **SOFTWARE VERIFICATION PLAN FOR GCS**

LESLIE A. DENT, ANITA M. SHAGNEA (Research Triangle Inst., Research Triangle Park, NC.), and KELLY J. HAYHURST Jan. 1990 112 p  
(NASA-TM-101668; NAS 1.15:101668) Avail: NTIS HC A06/MF  
A01 CSCL 09/2

This verification plan is written as part of an experiment designed to study the fundamental characteristics of the software failure process. The experiment will be conducted using several implementations of software that were produced according to industry-standard guidelines, namely the Radio Technical Commission for Aeronautics RTCA/DO-178A guidelines, Software Consideration in Airborne Systems and Equipment Certification, for the development of flight software. This plan fulfills the DO-178A requirements for providing instructions on the testing of each implementation of software. The plan details the verification activities to be performed at each phase in the development process, contains a step by step description of the testing procedures, and discusses all of the tools used throughout the verification process. Author

**N90-18065#** Sandia National Labs., Albuquerque, NM.

### **THE 59TH SHOCK AND VIBRATION SYMPOSIUM, VOLUME 2**

HENRY C. PUSEY, comp. and SALLIE C. PUSEY, comp. Oct. 1988 408 p Symposium held in Albuquerque, NM, 18-20 Oct. 1988; sponsored by DOD (Contract DE-AC04-76DP-00789) (AD-A214579; SAND-88-2473C-VOL-2; UC-13-VOL-2) Avail: NTIS HC A18/MF A03 CSCL 20/11

Some titles of articles presented in the volume are presented: Dynamic testing (STAR 63F Q-3 qualification vibration test); Correlation between vibration and computer operator response onboard a UH-1H helicopter; Shaker shock testing using nonstationary random transients; and High velocity impact testing of an accident resistant container using a large centrifuge; Shock (Pyrotechnic shock data reduction procedures and problems); Time domain analysis of pyrotechnic shock using resonant beam test apparatus; Equipment limitations in pyrotechnic shock testing;



Shock response spectrum anomalies which occur due to imperfections in the data; Fourier transform for almost any number of data points with reasonable run times; Shock spectrum for classes of excitations; Technical procedure for optimum shock hardening of aircraft support equipment; and Boundary integral technique for explosion bubble collapse analysis; Dynamic analysis (Modeling vibration transmission in a damped beam structure using statistical energy analysis); Solar array deployment nonlinear dynamics analysis; Experimental observations of low and zero gravity nonlinear fluid-spacecraft dynamics; Vibratory system dynamic analysis using a graphics based self-formulating program; and Design of upper atmosphere research satellite using transient loads analysis. Author

**N90-18070\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

**A STUDY OF THE STRUCTURAL EFFICIENCY OF FLUTED CORE GRAPHITE-EPOXY PANELS**

DAWN C. JEGLEY Jan. 1990 18 p  
(NASA-TM-101681; NAS 1.15:101681) Avail: NTIS HC A03/MF A01 CSCL 20/11

The structural efficiency of compression-loaded graphite-epoxy sandwich panels with fluted cores is studied to determine their weight saving potential. Graphite-epoxy equilateral triangular elements are used to construct the fluted cores for the sandwich panels. Two panel configurations are considered. One configuration has two layers of triangular elements in the fluted core and the second configuration has only one layer of triangular elements in the core. An optimization code is used to find the minimum weight design for each panel configuration. Laminate ply orientations are limited to approx. 45, 0, and 90 deg. A constraint on the axial stiffness is included in the design process so the panel will conform to typical constraints for aircraft wing structures. Minimum thickness requirements for each laminate and maximum allowable strains are also included. A comparison is made of the calculated structural efficiency of the fluted core panels to the structural efficiency of aluminum transport aircraft structures and simple blade-stiffened graphite-epoxy panels. Limited experimental results are also included for comparison with the analytical predictions and to identify the critical failure mechanisms of graphite-epoxy fluted-core sandwich panels. Author

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### GEOSCIENCES

Includes geosciences (general); earth resources; energy production and conversion; environment pollution; geophysics; meteorology and climatology; and oceanography.

**A90-24253**

**AIRCRAFT NOISE**

MICHAEL J. T. SMITH (Rolls-Royce, PLC, London, England) Cambridge and New York, Cambridge University Press, 1989, 370 p. refs  
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A comprehensive account is given of the factors affecting the generation of aircraft noise by subsonic and supersonic commercial aircraft airframes and the range of pure-jet, bypass fan, and propeller propulsion systems. A development history and current status evaluation is presented for methods of noise suppression in low and high-bypass airliner powerplants, especially during low-altitude takeoff and landing operations in the vicinity of airports. The cases of Concorde SST operations near airports, and the characteristics of supersonic-cruise 'sonic booms', are also discussed with a view to prospective SST development efforts. O.C.

**A90-25567**

**DEVELOPMENT OF AN AUTOMATED WINDSHEAR DETECTION SYSTEM USING DOPPLER WEATHER RADAR**

JAMES EVANS (MIT, Lexington, MA) and DONALD TURNBULL (FAA, Washington, DC) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1661-1673. Research supported by FAA. refs

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The US Federal Aviation Administration (FAA) is developing the Terminal Doppler Weather Radar (TDWR) system to determine the location and severity of LAWS (low-altitude windshear) phenomena and other weather hazards (e.g., tornadoes and turbulence) and to provide the pertinent information to real-time air traffic control users. The FAA program for developing and evaluating the TDWR is described, with emphasis on the resolution of key technical issues such as separation of the radar return due to the low-altitude weather phenomena from that caused by various clutter sources and the automatic detection of the phenomena by means of pattern recognition applied to images depicting the weather reflectivity and Doppler shift. These technical issues have been addressed using experimental data obtained using a testbed radar in representative meteorological regimes. The system performance has been assessed using numerous experimental windshear data sets with corresponding 'truth' developed by experienced radar meteorologists from a number of organizations. It is shown that the system provides very reliable detection of strong microbursts in a variety of environments with a gust-front detection capability that supports effective planning of airport runway use. I.E.

**A90-25572**

**ADVANCES IN WEATHER TECHNOLOGY FOR THE AVIATION SYSTEM**

JOHN MCCARTHY (National Center for Atmospheric Research, Boulder, CO) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1728-1734. Research supported by the National Center for Atmospheric Research and NSF. refs  
(Contract DTFA01-82-Y-10513)

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It is affirmed that there is a critical need for the development of aviation weather warning and forecast system products that give attention to storm-scale weather. This specifically addresses weather events that occur on the 0-2-h time and 0-5-mi space scales, which are significantly smaller than the scales used in today's weather system. Through a series of weather sensor modernization systems, including Doppler weather radar vertical wind profiling radars, automated surface weather-sensing stations, and advanced weather satellites, the capability to obtain high-resolution advanced weather products will be enhanced. Examples of both deficiencies in the current aviation weather system and expected new advanced products in a modernized weather system are given. For example, a precise 30-60-min thunderstorm point forecast should become available during the next decade. In addition, a series of fully automatic weather hazard warning products, including those for low-altitude wind shear, tornadoes, and turbulence, will become available for air traffic controllers and flight crews. It is noted that, once validated advanced weather products are routinely made available, it is incumbent upon the operational users of the aviation system to develop more definitive means of making operational decisions that improve both the safety and efficiency of the system. I.E.

**N90-17235\*#** National Aeronautics and Space Administration, Washington, DC.

**NASA AERODYNAMICS PROGRAM Annual Report, 1989**

BRUCE J. HOLMES, EDWARD SCHAIRER, GARY HICKS, STEPHEN WANDER, ISIAIAH BLANKSON, RAYMOND ROSE, LAWRENCE OLSON, and GEORGE UNGER Feb. 1990 445 p  
(Contract NASW-4430)  
(NASA-TM-4175; NAS 1.15:4175) Avail: NTIS HC A19/MF A03 CSCL 04/2

Presented here is a comprehensive review of the following aerodynamics elements: computational methods and applications,



## 13 GEOSCIENCES

computational fluid dynamics (CFD) validation, transition and turbulence physics, numerical aerodynamic simulation, drag reduction, test techniques and instrumentation, configuration aerodynamics, aeroacoustics, aerothermodynamics, hypersonics, subsonic transport/commuter aviation, fighter/attack aircraft and rotorcraft. Author

**N90-18125\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **THE 1985 AND 1986 DIRECT STRIKE LIGHTNING DATA,**

#### **PART 1**

KLAUS P. ZAEPFEL and HAROLD K. CARNEY Mar. 1988 500 p  
(NASA-TM-100533-PT-1; NAS 1.15:100533-PT-1) Avail: NTIS HC A21/MF A03 CSCL 04/2

Data waveforms are presented which were obtained during the 1985 and 1986 direct-strike lightning tests utilizing the NASA F-106B aircraft specially instrumented for lightning electromagnetic measurement. The aircraft was operated in the vicinity of the NASA Langley Research Center, Hampton, Virginia, in a thunderstorm environment in order to elicit lightning strikes. Electromagnetic field data and conduction currents on the aircraft were recorded for lightning. Author

**N90-18126\*#** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

### **THE 1985 AND 1986 DIRECT STRIKE LIGHTNING DATA,**

#### **PART 2**

KLAUS P. ZAEPFEL and HAROLD K. CARNEY Mar. 1988 472 p  
(NASA-TM-100533-PT-2; NAS 1.15:100533-PT-2) Avail: NTIS HC A20/MF A03 CSCL 04/2

Data waveforms are presented which were obtained during the 1985 and 1986 direct-strike lightning tests utilizing the NASA F-106B aircraft specially instrumented for lightning electromagnetic measurements. The aircraft was flown in the vicinity of the NASA Langley Research Center, Hampton, Virginia, in a thunderstorm environment in order to elicit lightning strikes. Electromagnetic field data and conduction currents on the aircraft were recorded for lightning. Author

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## MATHEMATICAL AND COMPUTER SCIENCES

Includes mathematical and computer sciences (general); computer operations and hardware; computer programming and software; computer systems; cybernetics; numerical analysis; statistics and probability; systems analysis; and theoretical mathematics.

**A90-23755#**

### **ON-LINE TEMPERATURE PROFILE DISPLAY SYSTEM**

K. VENKATARAJU, A. G. SATHEERATNAM, and R. RAMANATHAN (Gas Turbine Research Establishment, Bangalore, India) ASME, Gas Turbine and Aeroengine Congress and Exposition, Toronto, Canada, June 4-8, 1989. 7 p.  
(ASME PAPER 89-GT-10)

Combustor development depends on two important factors, namely combustor efficiency and exit temperature profile. A microprocessor based system has been designed to have on-line display of exit temperature profiles during the development testing of a gas turbine engine. The system acquires temperature data from thirty thermocouples around the circumference and at various radial positions of the engine. The signals from the thermocouples are fed to a microprocessor through an analog input subsystem. The microprocessor computes the temperatures, averages the values and plots the radial profile on a color graphic terminal. On the color graphic terminal, ideal temperature profiles for various engine speeds are drawn. On the ideal temperature profile, actual

temperature profiles are superimposed for various speeds during the testing of a gas turbine engine. In addition, circumferential profile is also plotted in off-line. Author

**A90-24101**

### **MEAN-SQUARE APPROXIMATION BY AN EVEN NONNEGATIVE POLYNOMIAL [SREDNEKVADRATICHNAIA APPOKSIMATSIIA CHETNYM NEOTRITSATEL'NYM POLINOMOM]**

S. N. SUPRUNENKO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 2, 1988, p. 70-84. In Russian. refs  
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A method for solving the problem of the mean-square approximation of a real function by a real even nonnegative polynomial is proposed. The method is based on the minimization of the approximation error with respect to the coefficients of the spectral factor of the approximating polynomial. It is shown that the solution can be obtained using unconditional-minimization algorithms. This approximation can be used to study aircraft control systems in the frequency domain. B.J.

**A90-24127**

### **APPLICATION OF THE MARS SYSTEM IN AIRCRAFT-STRUCTURE DESIGN [PRIMENENIE SISTEMY MARS V PROEKTIROVOCHNYKH RASCHETAKH AVIATSIONNYKH KONSTRUKII]**

A. B. KUDRIASHOV, E. K. LIPIN, A. N. SHANYGIN, and I. U. A. SHEVCHENKO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 71-80. In Russian. refs  
Copyright

An optimization subsystem has been developed for the selection of aircraft-structure design parameters in the framework of the MARS CAD system. This subsystem is used to optimize structures with strength constraints in the form of admissible stresses. Thicknesses and areas of finite-element cross sections of the computational model of the structure are used as the design parameters; it is possible to optimize structures made of composite materials. Some results of the system's application are presented. B.J.

**A90-25289#**

### **THREE-DIMENSIONAL ADAPTIVE GRID GENERATION ON A COMPOSITE-BLOCK GRID**

HYUN JIN KIM (Republic of Korea Air Force, Seoul) and JOE F. THOMPSON (Mississippi State University, Mississippi State) AIAA Journal (ISSN 0001-1452), vol. 28, March 1990, p. 470-477. Previously cited in issue 07, p. 1081, Accession no. A88-22225. refs  
(Contract F08635-84-C-02281)  
Copyright

**A90-25478#**

### **COMPARISONS AMONG GRID GENERATION USING ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS**

LIH-WU HOUNG and CHIN-KUAN HWANG (National Central University, Chung Li, Republic of China) Chinese Society of Mechanical Engineers, Journal (ISSN 0257-9731), vol. 10, Oct. 1989, p. 383-392. Sponsorship: National Science Council of the Republic of China. refs  
(Contract NSC-78-0401-E008-04)

The grid distributions generated by elliptic partial differential equations of different kinds are studied. Grids are generated around different bodies (symmetric airfoil, highly curved airfoil, and three-dimensional wing) by the Middlecoff (1980), Thames (1982), and Thomas (1982) methods. It is shown that the grids generated by the Middlecoff and Thomas methods are usually the same in C-type and H-type flowfields. In O-type flowfields, grids generated by Thames method are not clustered near the body. Nonlinear interpolation is used to calculate the interior controlled functions. The results show that the grid distributions are more smooth (and grids shocks are avoided) if a suitable weighting parameter is chosen. Author

A90-25563

**FUTURE ATC AUTOMATION AIDS BASED UPON AI TECHNOLOGY**

JOHN A. SCARDINA (FAA, Washington, DC), PI-YU RYBERG (Mitre Corp., McLean, VA), and ARTHUR GERSTENFELD (UFA, Inc., Newton, MA) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1625-1633. refs  
(Contract DTRS-573-86-C-00131)

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The authors discuss two knowledge-based systems that are currently under development by the Federal Aviation Administration, namely, a simulation system for air traffic controller training and an automated problem resolution capability that is the central feature of the Automated En Route Air Traffic Control System (AERA 2). For each of these systems, the manner in which knowledge-based system technology is applied is discussed, along with the knowledge bases. The process for building, refining, and evaluating the knowledge bases is also presented. In the air traffic controller training system, ATCoach, the representation of ATC knowledge has been shown to be highly beneficial for both ATC training and airspace modeling. In AERA 2 automated problem resolution (APR) evaluations, the AI/knowledge-based system technology has proven to be indispensable in the representation of the experts' knowledge and the effective factoring of the knowledge into APR. It is concluded that these application offer great potential for success and, consequently, represent only the first step in applying AI principles to ATC. I.E.

A90-25566

**ADVANCED AUTOMATION SYSTEM DESIGN**

RUSSELL A. BENEL, ROBERT D. DANCEY, JON D. DEHN, JAMES C. GUTMANN, and DONALD M. SMITH (IBM Corp., System Integration Div., Rockville, MD) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Nov. 1989, p. 1653-1660.

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The Advanced Automation System (AAS) is being developed for the US Federal Aviation Administration to provide air traffic control automation support well into the twenty-first century. The authors provide an overview of the AAS design and discuss key-requirement design drivers. The extremely high system-availability requirements are described, and the architectural, hardware, and software approaches to meeting them are discussed. The replacement of paper flight progress strips with an all-electronic display workstation for the air traffic controller has demanded a major effort in human engineering. The scope and results of this effort to date are described. I.E.

A90-25719

**COMPUTERS AND THE AEROSPACE ENGINEER**

LINDA E. TREGO Aerospace Engineering (ISSN 0736-2536), vol. 10, March 1990, p. 37-41.

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The use of computers in aerospace for design and analysis is described, and examples of project enhancements are presented. NASA is working toward the design of a numerical test cell that will allow integrated, multidisciplinary design, analysis, and optimization of propulsion systems. It is noted that with continuing advances in computer technology, including areas such as three-dimensional computer-aided design, finite element analysis, supercomputers, and artificial intelligence, the possibilities seem limitless for the aerospace engineer. Research projects are currently underway for design and/or reconfiguration of the V-22, B-767, SCRAMJET engines, F-16, and X29A using these techniques. R.E.P.

A90-25989\*# Georgia Inst. of Tech., Atlanta.

**APPROXIMATE LOOP TRANSFER RECOVERY METHOD FOR DESIGNING FIXED-ORDER COMPENSATORS**

ANTHONY J. CALISE and J. V. R. PRASAD (Georgia Institute of Technology, Atlanta) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 297-302. Research supported by the U.S. Army. Previously cited in issue 21, p. 3584,

Accession no. A88-50184. refs

(Contract NAG1-243)

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A90-25994#

**ROBUST CONTROL SYSTEM DESIGN SYNTHESIS WITH OBSERVERS**

TSUYOSHI OKADA, MASAHIKO KIHARA (Defense Academy, Yokosuka, Japan), and MASAKAZU IKEDA Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 337-342. refs

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A method of designing a robust controller including an observer for a multi-input/multi-output controlled system is presented. The well-known robustness of the optimal regulator is valid only when the regulator is constructed by full-state feedback, and this robustness is not guaranteed if an observer is introduced. In this study, a new output feedback loop is added to recover the robustness of the system with an observer and a precompensator is used to improve the response characteristics. Singular-value analysis is applied to improve the robustness of the synthesized system. An example for an aircraft is calculated, and good simulated results are demonstrated. Author

A90-25997#

**SIMULATOR MOTION-DRIVE ALGORITHMS - A DESIGNER'S PERSPECTIVE**

MEYER A. NAHON and LLOYD D. REID (Toronto, University, Canada) Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 13, Mar.-Apr. 1990, p. 356-362. Research supported by the Canadian Transportation Development Centre and NSERC. refs

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A comparative study has been conducted of the three flight simulator physical motion-generating software algorithms most commonly found in the literature: classical washout, optimal-control, and coordinated-adaptive; the comparisons involved pilot evaluations of the algorithms' implementations on a six-degree-of-freedom large transport aircraft simulator, giving attention to low altitude flight and ground maneuvering. The ease with which prospective algorithms can be refined to achieve high performance levels is identified as the most productive algorithm-design criterion. O.C.

A90-26022

**AUTOMATIC MESH GENERATION FOR COMPLEX THREE-DIMENSIONAL REGIONS USING A CONSTRAINED DELAUNAY TRIANGULATION**

TIMOTHY J. BAKER (Princeton University, NJ) Engineering with Computers (ISSN 0177-0667), vol. 5, Summer-Fall 1989, p. 161-175. Research supported by IMB Corp. refs

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This paper describes a method for generating tetrahedral meshes. The algorithm, based on the Delaunay triangulation, can treat objects of essentially arbitrary complexity. In order to preserve the surface triangulation of solid objects, it is necessary to override the Delaunay property and redefine the triangulation when points are introduced that are close to solid boundaries. Details of this constrained Delaunay algorithm are presented and an efficient implementation of the triangulation method is described. Techniques for controlling the distribution of mesh points and tetrahedron quality are also discussed. Author

A90-26225#

**THE ROLE OF EXPERT SYSTEMS IN AIRCRAFT SAFETY MANAGEMENT**

WILLIAM L. MARCH (Embry-Riddle Aeronautical University, Daytona Beach, FL) IN: International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 354-359. refs

This paper describes the basic elements of artificial intelligence (AI), such as heuristic search method, knowledge representation,

common-sense reasoning, logic, and related language tools, with particular attention given to the role of expert systems and AI in aviation-problem solving. An inference engine of an expert knowledge-based system (KBS) is described, which enables aviation researchers to make decisions by organizing and controlling steps necessary for solving problems related to aircraft accidents. The KBS relies on sophisticated problem techniques and vast stores of domain-specific knowledge, making it possible to solve problems that are beyond the capability of conventional language programs. I.S.

**A90-26476** European Space Agency. European Space Research and Technology Center, ESTEC, Noordwijk (Netherlands). **NUMERICAL GRID GENERATION IN COMPUTATIONAL FLUID MECHANICS '88; PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE, MIAMI BEACH, FL, DEC. 5-8, 1988**

J. HAEUSER, ED. (ESTEC, Noordwijk, Netherlands), PETER R. EISEMAN, ED. (Columbia University, New York), JOE F. THOMPSON, ED. (Mississippi State University, Mississippi State), and S. SENGUPTA, ED. Conference sponsored by NASA and USAF. Swansea, Wales, Pineridge Press, Ltd., 1988, 1085 p. For individual items see A90-26477 to A90-26557. Copyright

Theoretical and practical aspects of numerical grid generation are discussed in reviews and reports. Sections are devoted to general techniques; adaptive, orthogonal, and mapping methods; multiblock and multigrid methods; and unstructured grid generation. Also examined are specific applications to grids over aircraft, the Navier-Stokes equations, turbomachinery, computational hydraulics, and heat transfer and fluid flow. Topics addressed include mesh generation on parallel computers, patch-structured surface grids with dynamic curvature clustering, depth-adaptive grids using a control-function approach, unstructured-grid adaptation for nonconvex domains, zonal grid generation for fighter aircraft, hybrid coordinates for three-dimensional boundary-layer calculations, grid-induced computational flow separation, and automatic grid control in device simulation. T.K.

**A90-26481** **QUASI-THREE-DIMENSIONAL GRID GENERATION BY AN ALGEBRAIC HOMOTOPY PROCEDURE**

ANUTOSH MOITRA (High Technology Corp., Hampton, VA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 41-50. refs Copyright

A fast and versatile procedure for algebraic generating boundary conforming computational grids for use with finite-volume Euler flow solvers is presented. A semianalytic homotopic procedure is used to generate the grids. Grids generated in two-dimensional planes are stacked to produce quasi-three-dimensional grid systems. The body surface and outer boundary are described in terms of surface parameters. The method can be used for both internal and external flow configurations, the only constraint being that the body geometries be specified in two-dimensional cross-sections stationed along the longitudinal axis of the configuration. Techniques for treating problems arising in algebraic grid generation for geometries with sharp corners are discussed. Author

**A90-26484\*** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

**SURFACE GRID GENERATION FOR COMPLEX THREE-DIMENSIONAL GEOMETRIES**

RAYMOND CHING-CHUNG LUH (NASA, Ames Research Center, Moffett Field, CA) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 85-94. Previously announced in STAR as N89-13747. refs Copyright

An outline is presented for the creation of surface grids from primitive geometry data such as obtained from CAD/CAM systems. The general procedure is applicable to any geometry including full aircraft with wing, nacelle, and empennage. When developed in an interactive graphics environment, a code base on this procedure is expected to substantially improve the turn around time for generating surface grids on complex geometries. Results are shown for a general hypersonic airplane geometry. Author

**A90-26490** **HYPERBOLIC GRID GENERATION TECHNIQUES FOR BLUNT BODY CONFIGURATIONS**

KLAUS A. HOFFMANN, WALTER H. RUTLEDGE, and PATRICK E. RODI (Texas, University, Austin) IN: Numerical grid generation in computational fluid mechanics '88; Proceedings of the Second International Conference, Miami Beach, FL, Dec. 5-8, 1988. Swansea, Wales, Pineridge Press, Ltd., 1988, p. 147-156. Copyright

Application of hyperbolic grid generators to a representative blunt body is presented. Special modifications to the cell-area and arc-length hyperbolic schemes are discussed for simply-connected domains. Automated procedures for selecting geometric constraints are given for both schemes. Grid computation efficiency, clustering, and other features are also discussed. Author

**A90-26626** **ARRAY PROCESSOR SUPERCOMPUTERS**

J. L. POTTER and W. C. MEILANDER (Kent State University, OH) IEEE, Proceedings (ISSN 0018-9219), vol. 77, Dec. 1989, p. 1896-1914. refs Copyright

The authors describe the range of hardware variations of array processors, a form of simple instruction stream, multiple data stream architecture (SIMD), comparing and contrasting the significant differences among them and briefly illustrating the wide range of algorithms that can effectively utilize them. Three applications are reviewed. The first application, image convolution, represents the traditional numerically computationally intensive areas of application. SIMD array processors are sufficiently powerful to process digital imagery in real time easily. The second application, an example of real-time database management, is the air traffic control problem. The problem cannot be solved today by networks of computers that are successfully used in similar, less time-critical applications. With an array processor there is sufficient real time remaining after the present system tasks are accomplished to realize additional system enhancements. The third application area, graph algorithms, which is more theoretical, is representative of problems for which the simplicity of the array processor solution results in an execution time better than the best theoretical case for a conventional sequential implementation. I.E.

**A90-26755** **AUTOMATED PROCEDURE FOR CREATING FLIGHT-BY-FLIGHT SPECTRA**

ANTHONY G. DENYER (Rockwell International Corp., Los Angeles, CA) IN: Development of fatigue loading spectra. Philadelphia, PA, American Society for Testing and Materials, 1989, p. 79-98. refs Copyright

When the present computer code, which has been designed for rapid response to spectrum-generation requirements, is furnished with flight profiles and with their distribution over the aircraft's service life, it generates a randomly-sequenced flight-by-flight spectrum in terms of (1) loads, (2) load factors, or (3) stress, at a specified structural location. The basis of the software is a data base containing the frequency-distribution or load-factor occurrences representing gust and maneuver load cycles for various flight segments. Attention is presently given to the establishment of the data base from such sources as MIL-A-87221, analytically-derived load-factor data, and flight load records. O.C.

**N90-17348#** Rome Air Development Center, Griffiss AFB, NY.  
**RADC FAULT TOLERANT SYSTEM RELIABILITY  
 EVALUATION FACILITY In-House Report, Aug. 1988 - Feb.  
 1989**

JOSEPH CAROLI, FRANK FIELDSON, JACK HEWITT, and MATT  
 PLANO Oct. 1989 97 p  
 (AD-A215298; RADC-TR-89-165) Avail: NTIS HC A05/MF A01  
 CSCL 12/5

The Systems Reliability and Engineering Division of the Rome Air Development Center (RADC/RBE) is in the process of developing a Fault Tolerant System Reliability Evaluation Facility. The facility has the analysis/evaluation capability necessary to perform reliability modeling for virtually any fault tolerant system. RADC/RBE offers modeling expertise as a support service to DOD agencies with fault tolerant system reliability modeling needs. The facility relies heavily on the use of computer-aided reliability modeling tools. Since no single tool is perfect for every application, RADC/RBE has acquired several. They are CARE III, FASTER, HARP, MIREM, REST, and R and MA2T2. This functional capabilities plan analyzes the capabilities, strengths and weaknesses of each of the above tools. The overall capabilities of the facility are also discussed and sample modeling cases are provided. A survey of tools was also undertaken as part of this study. Short abstracts are provided for 27 modeling tools both new and old. GRA

**N90-18173#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**HYPERCUBE EXPERT SYSTEM SHELL-APPLYING  
 PRODUCTION PARALLELISM M.S. Thesis**

WILLIAM A. HARDING Dec. 1989 134 p  
 (AD-A215762; AFIT/GCS/ENG/89D-6) Avail: NTIS HC A07/MF  
 A01 CSCL 12/7

This research investigation proposes a hypercube design which supports efficient symbolic computing to permit real-time control of an air vehicle by an expert system. Design efforts are aimed at alleviating common expert system bottlenecks, such as the inefficiency of symbolic programming languages like Lisp and the disproportionate amount of computation time commonly spent in the match phase of the expert system match-select-act cycle. Faster processing of Robotic Air Vehicle (RAV) expert system software is approached through: (1) fast production matching using the state-saving Rete match algorithm, (2) efficient shell implementation using the C-Programming Language, and (3) parallel processing of the RAV using multiple copies of a serial expert system shell. In this investigation, the serial C-Language Integrated Production System (CLIPS) shell is modified to execute in parallel on the iPSC/2 Hypercube. Speedups achieved using this architecture are quantified through theoretical timing analysis, and comparison with serial architecture performance results, with earlier designs' performance results, with best case results and with goal performance. GRA

**N90-18181#** Washington Univ., Seattle. Dept. of Applied Mathematics.

**NUMERICAL ALGORITHMS FOR PARALLEL COMPUTERS  
 Final Technical Report, 1 May 1986 - 31 Aug. 1989**

LOYCE M. ADAMS 31 Aug. 1989 11 p  
 (Contract AF-AFOSR-0154-86; AF PROJ. 2304)  
 (AD-A216812; AFOSR-89-1685TR) Avail: NTIS HC A02/MF A01  
 CSCL 12/1

Throughout the duration of this grant, progress has been made on five fronts: analysis of parallel iterative methods using Fourier analysis techniques, preconditioners for linear systems on parallel architectures, numerical grid generation algorithms for fighter aircraft configurations, parallel domain decomposition algorithms for symmetric eigenvalue problems, and parallel language design issues from an applications point of view. GRA

**N90-18212#** Air Force Inst. of Tech., Wright-Patterson AFB, OH. School of Engineering.

**A FRACTIONAL CALCULUS MODEL OF AEROELASTICITY  
 M.S. Thesis**

DAVID V. SWINNEY Dec. 1989 60 p  
 (AD-A216244; AFIT/GA/ENY/89D-5) Avail: NTIS HC A04/MF  
 A01 CSCL 20/4

This thesis introduces a new model of aeroelastic behavior. It simplifies the unsteady aerodynamic force expressions for a flat plate by employing fractional order time derivatives to create a compact fractional order polynomial model of Theodorsen's function. This model is used to reduce the system equations of motion to a single fractional derivative eigenvalue problem. The eigenvalue problem is solved at increasing airspeeds to produce a root locus plot of system stability using airspeed as a gain. This method is shown to yield accurate system instability speeds. GRA

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## PHYSICS

Includes physics (general); acoustics; atomic and molecular physics; nuclear and high-energy physics; optics; plasma physics; solid-state physics; and thermodynamics and statistical physics.

**A90-23937\*** National Aeronautics and Space Administration. Langley Research Center, Hampton, VA.

**REDUCTION OF BLADE-VORTEX INTERACTION NOISE  
 THROUGH HIGHER HARMONIC PITCH CONTROL**

THOMAS F. BROOKS, EARL R. BOOTH, JR. (NASA, Langley Research Center, Hampton, VA), J. RALPH JOLLY, JR. (Planning Research Corp., Hampton, VA), WILLIAM T. YEAGER, JR., and MATTHEW L. WILBUR (U.S. Army, Aviation Systems Command, Hampton, VA) American Helicopter Society, Journal (ISSN 0002-8711), vol. 35, Jan. 1990, p. 86-91. Previously announced in STAR as N89-27465. refs

Copyright

An acoustics test using an aeroelastically scaled rotor was conducted to examine the effectiveness of higher harmonic blade pitch control for the reduction of impulsive blade-vortex interaction (BVI) noise. A four-bladed, 110 in. diameter, articulated rotor model was tested in a heavy gas (Freon-12) medium in Langley's Transonic Dynamics Tunnel. Noise and vibration measurements were made for a range of matched flight conditions, where prescribed (open-loop) higher harmonic pitch was superimposed on the normal (baseline) collective and cyclic trim pitch. For the inflow-microphone noise measurements, advantage was taken of the reverberance in the hard walled tunnel by using a sound power determination approach. Initial findings from on-line data processing for three of the test microphones are reported for a 4/rev (4P) collective pitch control for a range of input amplitudes and phases. By comparing these results to corresponding baseline (no control) conditions, significant noise reductions (4 to 5 dB) were found for low-speed descent conditions, where helicopter BVI noise is most intense. For other rotor flight conditions, the overall noise was found to increase. All cases show increased vibration levels.

Author

**A90-23974**

**ANGULAR FEATURE MAPPING - AN OPTICAL METHOD**

YORAM NAOR and JOSEPH SHAMIR (Technion - Israel Institute of Technology, Haifa) Applied Optics (ISSN 0003-6935), vol. 29, Feb. 10, 1990, p. 713-716.

Copyright

A pattern-recognition technique for estimating and mapping the intersection angles of line segments in an image is developed analytically and demonstrated. An incoherent slightly defocused imaging system is combined with a thresholding operation in which the scale-invariant features (angles) are analyzed via a rotation-invariant algorithm. The derivation of the governing equations is outlined, and results obtained using a TV camera and an electronic thresholding device on outline images of aircraft

are presented graphically. The shift, scale, and rotation invariance of the feature-extraction process is verified. T.K.

**A90-24117****OPTIMIZATION OF THE SOUND-ABSORPTION LINING PARAMETERS OF AN EJECTOR JET MUFFLER**

[OPTIMIZATSIYA PARAMETROV

ZVUKOPOGLOSHCHAIUSHCHEI OBLITSOVKI

EZHEKTORNOGO GLUSHITELIA SHUMA STRUI]

O. V. LEBEDEVA and Z. N. NAUMENKO TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 3, 1988, p. 110-114. In Russian. refs

Copyright

A method for the optimization of the parameters of a sound-absorption lining is described with reference to a simple ejector muffler using basalt fiber as the sound absorption material. It is shown that, in the frequency range investigated, optimum results are obtained with a 10-mm-thick basalt fiber layer. The additional reduction is sound level resulting from the lining optimization is 5-8 dB. V.L.

**A90-24125****ACOUSTIC NOISE EMITTED FROM VESSELS IN AN IMPULSE-TYPE WIND TUNNEL [AKUSTICHESKII SHUM, IZLUCHAEMYI EMKOST'IU AERODINAMICHESKOI TRUBY IMPUL'SNOGO DEISTVIA]**

V. IA. BEZMENOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 52-61. In Russian. refs

Copyright

A method for determining the level of acoustic noise emitted by an impulse-type wind tunnel is developed which is based on results of tests in a model facility. It is shown that the radiation intensity is defined by parameters reflecting the ratio of specific impulses acting on the walls of interior vessels and the rate of their filling by gas. B.J.

**A90-24132****INVESTIGATION OF WALL PRESSURE PULSATIONS DURING THE PASSIVE CONTROL OF SHOCK/BOUNDARY LAYER INTERACTION [IZUCHENIE PRISTENOCHNYKH PUL'SATSII DAVLENIIA PRI PASSIVNOM UPRAVLENII VZAIMODEISTVIEM SKACHKA UPLOTNENIIA S POGRANICHNYM SLOEM]**

S. A. KOVAL'NOGOV, V. M. FOMIN, and G. K. SHAPOVALOV TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 19, no. 4, 1988, p. 116-121. In Russian.

Copyright

Wall pressure pulsations during the passive control of shock/boundary layer interaction on a supercritical profile were investigated in a low-turbulence transonic wind tunnel. It is shown that the integral level of the pulsations can be reduced by injection of air from under the shock through a porous or two-slit surface. This in turn leads to a reduction of aeroacoustic loads acting on the wing profile. B.J.

**A90-25872#****SIMULATION OF SOUND PROPAGATION IN AXISYMMETRIC JET**

YASUJI TSUBAKISHITA and TAKAO YOSHIKAWA (Osaka University, Japan) IN: ISCFD Nagoya 1989 - International Symposium on Computational Fluid Dynamics, 3rd, Nagoya, Japan, Aug. 28-31, 1989, Technical Papers. Nagoya, Japan, Japan Society of Computational Fluid Dynamics, 1989, p. 1132-1137. refs

The structure of the radiated acoustic wavefield of an axisymmetric subsonic jet, a problem relevant to aircraft, and the effect of the inhomogeneous flow on the directivity of the far-field intensity are examined using a fourth-order accurate finite difference solution of the Euler equations. The flow quantities are divided into the mean flow quantities and the fluctuations due to the sound wave. The governing equations for fluctuations are derived by linearizing the unsteady Euler equations about a steady, compressible mean flow. The numerical scheme used for the fluctuations is a modified version of the MacCormack scheme

which is second-order accurate in time and fourth-order accurate in space. The method is reliable and accurate in predicting sound wave propagation through complex mean flow fields. C.D.

**A90-26138#****ACOUSTIC CHARACTERISTICS OF COUNTERROTATING UNDUCTED FANS FROM MODEL SCALE TESTS**

B. A. JANARDAN and P. R. GLIEBE (GE Aircraft Engines, Cincinnati, OH) Journal of Aircraft (ISSN 0021-8669), vol. 27, March 1990, p. 268-275. Previously cited in issue 13, p. 1944, Accession no. A89-33769. refs

Copyright

**A90-26931#****AN APPROXIMATION MODEL FOR THE PERFORMANCE AND ACOUSTIC PREDICTIONS OF COUNTERROTATING PROPELLER CONFIGURATIONS**

BRETT W. DENNER and KENNETH D. KORKAN (Texas A & M University, College Station) AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 19 p. refs (AIAA PAPER 90-0282) Copyright

An approximate method was developed to analyze and predict the acoustics of a counterrotating propeller configuration. The method employs the analytical techniques of Lock and Theodorsen as described by Davidson to predict the steady performance of a counterrotating configuration. Then, a modification of the method of Lesieur is used to predict the unsteady forces on the blades. Finally, the steady and unsteady loads are used in the numerical method of Succi to predict the unsteady acoustics of the propeller. The numerical results are compared with experimental acoustic measurements of a counterrotating propeller configuration by Gazzaniga operating under several combinations of advance ratio, blade pitch, and number of blades. It has been determined that the noise levels of the even harmonics are relatively independent of direction whereas the noise levels of the odd harmonics are extremely dependent on azimuthal direction in the horizontal plane. The equations of Succi are examined to explain this behavior.

Author

**N90-17409#** BBN Systems and Technologies Corp., Canoga Park, CA.

**NOISE AND SONIC BOOM IMPACT TECHNOLOGY. EFFECTS OF AIRCRAFT NOISE AND SONIC BOOMS ON STRUCTURES: AN ASSESSMENT OF THE CURRENT****STATE-OF-KNOWLEDGE Final Report, Sep. 1987 - Aug. 1988**

JERALD M. HABER, DAVID NAKAKI, CRAIG TAYLOR, GEORGE KNIPPRATH, VIJAY KOPPARAM, and MARK LEGG Feb. 1989 99 p

(Contract F33615-86-C-0530; AF PROJ. 3037)

(AD-A213919; BBN-6830; HSD-TR-89-002) Avail: NTIS HC

A05/MF A01 CSCL 20/1

A comprehensive literature search was performed regarding the effect of aircraft noise and sonic boom on structures. The initial phase of this search identified approximately 2,500 citations that were reviewed for suitability for the Assessment System for Aircraft Noise (Asan); 635 citations were selected for inclusion in the ASAN citation database. Of those citations included, 144 were identified to be of sufficient importance to include abstracts in the database. Critical reviews for 40 citations appear within the database; 4 of these citations are controversial and were reviewed by three independent reviewers. The remaining articles cover the following topics: conventional structures, cumulative damage, terrain effects, metastructural effects, unconventional structures, and low frequency noise effects. This report documents the methodology used to develop the database. In addition, it presents a synopsis of what is known about the effects of aircraft noise and sonic boom on structures, and identifies the technology gaps for each of the listed topics. GRA

**N90-17410#** BBN Systems and Technologies Corp., Canoga Park, CA.

**NOISE AND SONIC BOOM IMPACT TECHNOLOGY. INITIAL DEVELOPMENT OF AN ASSESSMENT SYSTEM FOR AIRCRAFT NOISE (ASAN). VOLUME 1: EXECUTIVE SUMMARY Final Report, 12 Feb 1987 - 31 Jul. 1989**

SANFORD FIDELL, NICOLAAS REDDINGIUS, MICHAEL HARRIS, and ANDREW B. KUGLER Jun. 1989 24 p  
(Contract F33615-86-C-0530)  
(AD-A214164; BBN-6624-VOL-1; HSD-TR-89-010-VOL-1) Avail: NTIS HC A03/MF A01 CSCL 20/1

This is the first volume of a four volume report describing the development of a preliminary prototype version of an Assessment System for Aircraft Noise (ASAN). ASAN is a software system intended to assist members of the United States Air Force environmental planning community to comply with noise-related aspects of the environment impact assessment process required by the National Environmental Policy Act (NEPA) of 1969 and other regulations. GRA

**N90-17411#** BBN Systems and Technologies Corp., Canoga Park, CA.

**NOISE AND SONIC BOOM IMPACT TECHNOLOGY. INITIAL DEVELOPMENT OF AN ASSESSMENT SYSTEM FOR AIRCRAFT NOISE (ASAN). VOLUME 2: SYSTEM DESIGN STRATEGY Final Report, 12 Feb. 1987 - 31 Jul. 1989**

SANFORD FIDELL, NICOLAAS REDDINGIUS, MICHAEL HARRIS, and B. ANDREW KUGLER Jun. 1989 57 p  
(Contract F33615-86-C-0530; AF PROJ. 3037)  
(AD-A214454; HSD-TR-89-010-VOL-2) Avail: NTIS HC A04/MF A01 CSCL 12/7

This is the second volume of a four volume report summarizing the development and current contents of a preliminary prototype version of an Assessment System for Aircraft Noise (ASAN). ASAN is a computer-based system intended to assist members of the United States Air Force (USAF) environmental planning community in addressing noise-related issues in developing environmental impact analysis documents, in compliance with USAF and other regulations, especially the National Environmental Policy Act (NEPA) of 1969. This volume describes the development and capabilities of the preliminary prototype version of ASAN and recommends actions needed to develop a final prototype version. GRA

**N90-17412#** BBN Systems and Technologies Corp., Canoga Park, CA.

**NOISE AND SONIC BOOM IMPACT TECHNOLOGY. INITIAL DEVELOPMENT OF AN ASSESSMENT SYSTEM FOR AIRCRAFT NOISE (ASAN). VOLUME 3: TECHNICAL DESCRIPTION Final Report, 12 Feb. 1987 - 31 Jul. 1989**

SANFORD FIDELL, NICOLAAS REDDINGIUS, MICHAEL HARRIS, and B. ANDREW KUGLER Jun. 1989 229 p  
(Contract F33615-86-C-0530; AF PROJ. 3037)  
(AD-A214455; HSD-TR-89-010-VOL-3) Avail: NTIS HC A11/MF A02 CSCL 12/5

This is the third volume report summarizing the development and current contents of a preliminary prototype version of an Assessment System for Aircraft Noise (ASAN). ASAN is a computer-based system intended to assist members of the United States Air Force (USAF) environmental impact analysis documents, in compliance with USAF and other regulations, especially the National Environmental Policy Act (NEPA) of 1969. This volume contains the specifications for the preliminary prototype ASAN software. GRA

**N90-17413\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

**PREDICTED AND MEASURED BOUNDARY LAYER REFRACTION FOR ADVANCED TURBOPROP PROPELLER NOISE**

JAMES H. DITTMAR and EUGENE A. KREJSA Jan. 1990 20 p

(NASA-TM-102365; E-5081; NAS 1.15:102365) Avail: NTIS HC A03/MF A01 CSCL 20/1

Currently, boundary layer refraction presents a limitation to the measurement of forward arc propeller noise measured on an acoustic plate in the NASA Lewis 8- by 6-Foot Supersonic Wind Tunnel. The use of a validated boundary layer refraction model to adjust the data could remove this limitation. An existing boundary layer refraction model is used to predict the refraction for cases where boundary layer refraction was measured. In general, the model exhibits the same qualitative behavior as the measured refraction. However, the prediction method does not show quantitative agreement with the data. In general, it overpredicts the amount of refraction for the far forward angles at axial Mach number of 0.85 and 0.80 and underpredicts the refraction at axial Mach numbers of 0.75 and 0.70. A more complete propeller source description is suggested as a way to improve the prediction method. Author

**N90-18225#** Stanford Univ., CA. Dept. of Mechanical Engineering.

**DIRECT NUMERICAL SIMULATION OF AERODYNAMIC NOISE Annual Progress Report No. 1**

PARVIZ MOIN, SANJIVA K. LELE, and TIM COLONIUS 29 Sep. 1989 39 p  
(Contract N00014-88-K-0592)

(AD-A214122) Avail: NTIS HC A03/MF A01 CSCL 20/1

Direct Numerical Simulation of Aerodynamic Noise is a part of an overall research program in compressible turbulence including the study of the physics of compressible turbulence, shock turbulence interactions, reacting flows with heat release, and aerodynamic sound generation in shear flows. The objective in aerodynamic sound generation is to use direct numerical simulations as a tool to study the noise generation processes directly, specifically answer the following questions: (1) Can one relate particular flow regions and events to the far field noise; (2) What regions are the dominant contributors to the far field noise; (3) What is the role played by pairing process in noise generation; (4) How important are the small scales to the noise generation; and (5) What processes control the far field directivity pattern. To answer these questions in shear flows, first study the acoustics of simple building block flows. The discussion below presents recent results obtained for one of the building block flows, the scattering of sound by a vortex. A short discussion of numerical accuracy is also given. Finally, results are presented for aerodynamic sound generation from a 2-D temporal mixing layer. GRA

**N90-18228\*#** Texas A&M Univ., College Station. Dept. of Aerospace Engineering.

**AN APPROXIMATE MODEL FOR THE PERFORMANCE AND ACOUSTIC PREDICTIONS OF COUNTERROTATING PROPELLER CONFIGURATIONS M.S. Thesis**

BRETT WILLIAM DENNER Dec. 1989 182 p  
(Contract NAG3-354)

(NASA-CR-180667; NAS 1.26:180667) Avail: NTIS HC A09/MF A01 CSCL 20/1

An approximate method was developed to analyze and predict the acoustics of a counterrotating propeller configuration. The method employs the analytical techniques of Lock and Theodorsen as described by Davidson to predict the steady performance of a counterrotating configuration. Then, a modification of the method of Lesieur is used to predict the unsteady forces on the blades. Finally, the steady and unsteady loads are used in the numerical method of Succi to predict the unsteady acoustics of the propeller. The numerical results are compared with experimental acoustic measurements of a counterrotating propeller configuration by Gazzaniga operating under several combinations of advance ratio, blade pitch, and number of blades. In addition, a constant-speed commuter-class propeller configuration was designed with the Davidson method and the acoustics analyzed at three advance ratios. Noise levels and frequency spectra were calculated at a number of locations around the configuration. The directivity patterns of the harmonics in both the horizontal and vertical planes were examined, with the conclusion that the noise levels of the

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even harmonics are relatively independent of direction whereas the noise levels of the odd harmonics are extremely dependent on azimuthal direction in the horizontal plane. The equations of Succi are examined to explain this behavior. Author

**N90-18229\*#** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, OH.

### **UNSTEADY EULER ANALYSIS OF THE FLOW FIELD OF A PROPPAN AT AN ANGLE OF ATTACK**

M. NALLASAMY (Sverdrup Technology, Inc., Cleveland, OH.) and J. F. GROENEWEG 1990 19 p Presented at the 28th Aerospace Sciences Meeting, Reno, NV, 8-11 Jan. 1990; sponsored by AIAA (NASA-TM-102426; E-5191; NAS 1.15:102426; AIAA-90-0339) Avail: NTIS HC A03/MF A01 CSCL 20/1

The effects of angle of attack of a propan on the blade loading and details of the flow field by solving the unsteady three-dimensional Euler equations are examined. The configuration considered is the SR7L propeller at cruise condition and the inflow angles considered are 4.6 degrees, 1.6 degrees and -0.4 degrees. The results indicate that the blade response is nearly sinusoidal at low inflow angles (1.6 degrees and -0.4 degrees) and significant deviations from sinusoidal behavior occur at an inflow angle of 4.6 degrees due to the presence of strong shocks on both suction and pressure surfaces of the blade. The detailed flow in the blade passages shows that a shock formed on the suction surface during the highly loaded portion of the revolution extends across the passage to the pressure surface. An increase in inflow angle results in an increase in blade loading on the down-going side and a decrease in loading on the up-going side. Author

**N90-18233\*#** Boeing Commercial Airplane Co., Seattle, WA. New Product Development Organization.

### **FLIGHT SURVEY OF THE 757 WING NOISE FIELD AND ITS EFFECTS ON LAMINAR BOUNDARY LAYER TRANSITION. VOLUME 3: EXTENDED DATA ANALYSIS**

Mar. 1988 286 p (Contract NAS1-15325) (NASA-CR-178419; NAS 1.26:178419; D6-53196-3-VOL-3) Avail: NTIS HC A13/MF A02 CSCL 20/1

A flight program was completed in June of 1985 using the Boeing 757 flight research aircraft with an NLF glove installed on the right wing just outboard of the engine. The objectives of this program were to measure noise levels on the wing and to investigate the effect of engine noise on the extent of laminar flow on the glove. Details of the flight test program and results are contained in Volume 1 of this document. Tabulations and plots of the measured data are contained in Volume 2. The present volume contains the results of additional engineering analysis of the data. The latter includes analysis of the measured noise data, a comparison of predicted and measured noise data, a boundary layer stability analysis of 21 flight data cases, and an analysis of the effect of noise on boundary layer transition. Author

International Symposium on Aviation Psychology, 5th, Columbus, OH, Apr. 17-20, 1989, Proceedings. Volume 1. Columbus, OH, Ohio State University, 1989, p. 425-432.

This paper reviews NASA's Aviation Safety Reporting System incident data for a two-year period in order to identify the frequency of air-ground information transfer errors and the factors associated with their occurrence. Of the more than 14,000 primary reports received during the 1985 and 1986 reporting period, one out of four reports concerned problems of information transfer between aircraft and ATC. Approximately half of these errors were associated directly or indirectly with aircraft deviations from assigned heading or altitude. The majority of incidents cited some human-system problem such as workload, cockpit distractions, etc., as the primary contributing factor. Improvements in air-ground information transfer using existing and future (e.g., data link) technology are proposed centering on the development and application of user-centered information management principles. Author

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## SOCIAL SCIENCES

Includes social sciences (general); administration and management; documentation and information science; economics and cost analysis; law and political science; and urban technology and transportation.

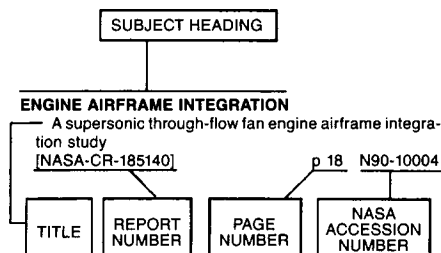
**A90-26235\*#** National Aeronautics and Space Administration. Ames Research Center, Moffett Field, CA.

### **AIR-GROUND INFORMATION TRANSFER IN THE NATIONAL AIRSPACE SYSTEM**

ALFRED T. LEE (NASA, Ames Research Center, Moffett Field, CA) and SANDRA LOZITO (San Jose State University, CA) IN:



## Typical Subject Index Listing



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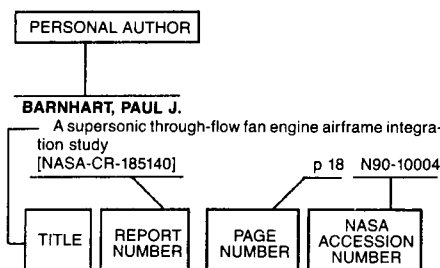
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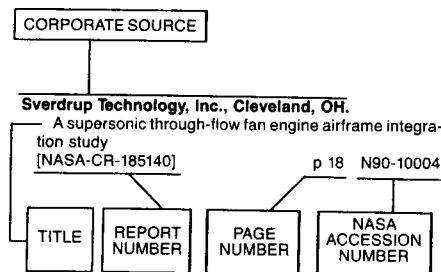
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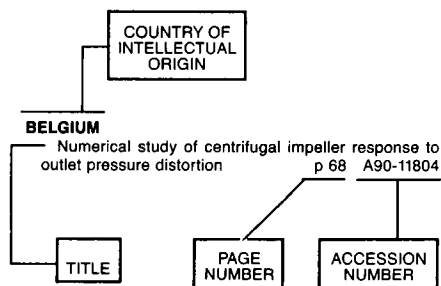
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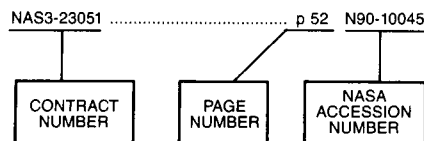
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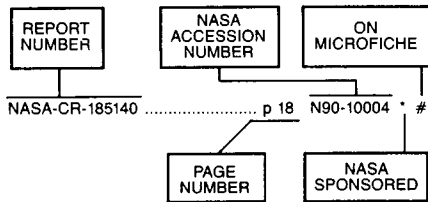
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AERONAUTICAL ENGINEERING / A Continuing Bibliography (Supplement 253)

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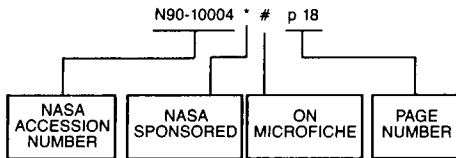
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